

## APPENDIX H

### Analysis of Mine Site Geochemistry

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## APPENDIX H

### Analysis of Mine Site Geochemistry

This appendix contains additional background and detail related to geochemical effects at the mine site for Alternative 2, and is provided in support of the water quality analysis, water management decisions, and water treatment needs discussed in Section 3.7, Water Quality.

#### 1. Infrastructure and Processes

Under Alternative 2, geochemical environmental consequences are tied to several components of the Donlin Gold Project, specifically:

- The Waste Rock Facility (WRF);
- The North Overburden (NOB) and South Overburden (SOB) Stockpiles;
- Low-grade Ore Stockpile;
- Lower and Upper Contact Water Dam (CWD);
- Haul roads built with waste rock;
- The Tailings Storage Facility (TSF); and
- Open Pit and Pit Lake.

With the exception of haul roads, each of these components is considered in general in this section of the appendix, and described in more detail for each project stage in Sections 2 (Construction), 3 (Operations and Maintenance), and 4 (Closure, Reclamation, and Monitoring). The haul roads are discussed in the main EIS in Section 3.7.3.2.2, Surface Water Quality, and Section 3.7.3.2.3, Groundwater Quality.

#### 1.1 Waste Rock Facility

Alternative 2 would generate approximately 3 billion tons of waste rock, of which approximately 2.5 billion tons are planned to be placed in a proposed WRF that would ultimately cover an area of 3.5 square miles (SRK 2012a). As discussed in EIS Section 3.7.2.4.1, Geochemical Characterization – Waste Rock, Donlin Gold has conducted an extensive geochemical characterization of the waste rock that would be generated by the proposed mining. The results indicated that most of the waste rock has metal leaching potential, especially for arsenic, selenium, and antimony, which are soluble in the neutral to basic solutions likely to be generated by the non-acid generating (NAG) rocks (SRK 2007; SRK 2011). The characterization also indicated that about 7 to 8 percent of the waste rock is potentially acid generating (PAG) (Table H-1). Both metal leaching (ML) fluids and acid rock drainage (ARD) could react with local soils and rocks and negatively impact surface and groundwater in the vicinity of the site if not controlled and managed.

Table H-1: Waste Rock Tonnage Estimates

Waste Rock Classification	Tonnage (million tons)	Percent of Total
NAG 1-4 and OVB	2,823.153	92.63
PAG 5	87.113	2.86
PAG 6	135.065	4.43
PAG 7	2.555	0.08
Total Waste Rock	3,047.886	100

Source: SRK 2012e, Table 3-5.

Management of the waste rock is planned to be based on identification and classification of the various waste rock categories discussed below (SRK 2012e).

- *Overburden.* Overburden is planned to be used in construction, as cover for the isolated cells of PAG 6 waste rock, and for final site reclamation. Excess overburden is planned to be placed in the American Creek drainage WRF. Geochemical testing of 33 overburden samples (see EIS Section 3.7.2.4.2, Water Quality) suggests that the overburden tends to be pH-inert, with essentially no neutralizing potential or acid generating potential. However, there may be a potential for leaching of arsenic and other metals from overburden taken from directly above the pit area (BGC 2011g), and possible ARD formation from the same overburden taken from lower depths.
- *NAG 1-4.* Most of the NAG 1-4 rocks would be placed in the unlined American Creek drainage WRF (Figure 2.3-6, EIS Chapter 2, Alternatives). Rocks of these classifications would also be used in construction of haul roads and as construction material for unlined portions of the TSF as rockfill, filter zones, riprap, and underdrain rockfill. The NAG rocks were found to have no potential to generate ARD (EIS Table 3.7-16, Water Quality). However, they do have the potential to generate drainage with concentrations of arsenic above applicable water quality criteria (AWQC) (SRK 2007). Because antimony and mercury were found to be positively correlated with arsenic and typically show geochemical coherence with arsenic, these constituents could also potentially leach from these rocks.
- *PAG 5.* The PAG 5 rock has the potential to generate ARD after several decades. Modeling of drainage chemistry suggests that approximately 81 percent of the PAG 5 rock can be blended with the NAG rock in the WRF, provided that the blending is managed to result in intimate contact between the rock types (SRK 2012e). The remaining 19 percent would be used for construction of the TSF causeway and as pit backfill. Further discussion of the design of the American Creek WRF is given in EIS Section 2.3.2.1.9, Chapter 2, Alternatives.
- *PAG 6.* The PAG 6 rock has the potential to generate acid over a relatively short time period (possibly less than a decade) (SRK 2007, 2011). This rock is to be placed in isolated cells in Rob's Gulch and Unnamed Gulch, between the main American Creek drainage WRF and the open pit (BGC 2011b). An intermediate cover of approximately 3 feet of low-permeability terrace gravel and/or colluvium would be placed over each 100-foot lift to direct runoff and reduce infiltration (BGC 2011a; SRK 2012e). The design

of the PAG cells is discussed further in Chapter 2, Section 2.3.2.1. The PAG 6 rock mined near the end of mine life would be used as backfill into the ACMA Pit.

- *PAG 7.* The PAG 7 rock has the potential to generate acid in a few years or less (SRK 2007, 2012b). It is not planned to be put into the WRF, but would be stored temporarily in the low-grade ore stockpile until it can be transferred as backfill into the ACMA Pit (SRK 2012e).

## 1.2 Tailings Storage Facility

The tailings formed from proposed ore processing are planned to be deposited as slurry in a conventional TSF with a fully lined impoundment (SRK 2012a). The TSF is planned to be located in the Anaconda Creek valley south of the American Creek WRF (Figure 2.3-7, Chapter 2, Alternatives). The TSF design is discussed more fully in Section 2.3.2.1.8, Chapter 2, Alternatives.

According to the Water Resources Management Plan (SRK 2012b), tailings from the mine site would be comprised of about 64 percent water and 36 percent solids by weight. Three phases of metallurgical testing were conducted. A blend of detoxified CIL tailings and neutralized autoclave acidic liquor was used to create the final tailings in order to provide samples that were reasonably representative of both the ore and the complete metallurgical process. The chemistry of the solids portion of the pilot final tailings product is given in Table H-2; while the liquor chemistry is given in Table H-3 and Table H-4.

As discussed in Section 3.7.2.4.4, Water Quality, Tailings, the tailings from the Phase 2 pilot testing are more representative of the combined ore types that would be processed through the process facilities. Comparison of the Phase 2 results with the prior tests show the variation across ore samples. Based on the three sets of testing, the tailings solids tend to be elevated with respect to arsenic and antimony compared with their average concentrations in the rhyodacite rocks to be mined. (Compare Table H-2 with EIS Table 3.7-19, Water Quality) The tailings liquor pH is circumneutral (7.6 to 7.7), but could have concentrations of sulfate in the range of 2,500 to 4,600 mg/L and arsenic concentrations in the range of 0.43 to 1.1 mg/L. Compared with the most stringent AWQC, the tailings liquor is elevated for cobalt, mercury, manganese, molybdenum, antimony, and selenium (SRK 2012b). Due to high mercury levels, the process plant design would include a dosage facility to allow chemical addition to precipitate mercury as a stable mercury sulfide compound that would remain with the tailings solids in the TSF (SRK 2012b).

The Donlin Gold Project is expected to have a water surplus during operations under average precipitation conditions. Surplus water would be stored in the TSF pond until closure, when it will be pumped to the open pit. Originally, the project was conceived to have a no-discharge TSF. However, because of the water surplus, an advanced water treatment (AWT) scheme was developed by Hatch (2015). (The AWT is discussed in Section 3.7.3.2.2, of the EIS) Based on the AWT, a water management system was designed to minimize the amount of contact water and to treat and discharge various mine water sources, as needed, to minimize build-up of water in the TSF pond (BGC 2015f). Under this system, the concentrations of constituents in the TSF pond and pore water are predicted to increase beyond the results shown in Table H-1 and Table H-2 by as much as a factor of three over the mine life, due to re-circulation of tailings water into the flotation and hydrometallurgical processes (SRK 2015a). The predicted chemistry of these

waters is discussed further in Section 3.6 of this appendix (Operations—Tailings Storage Facility).

Table H-2: Final Plant Tailings Solids Analysis of the Pre-Feasibility, Phase 1 Feasibility, and Phase 2 Feasibility Pilot Tests

Parameter	Unit	Feasibility Pilot (Phase 2) Final Tailings Filtrate 2007	Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007	Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006
Chloride	%	<0.01	<0.01	<0.01
Fluoride	%	0.01	0.01	0.01
Aluminum	mg/Kg	63,000	69,000	71,000
Antimony	mg/Kg	120	230	250
Arsenic	mg/Kg	910	2,900	3,400
Barium	mg/Kg	640	520	520
Beryllium	mg/Kg	2.2	2	2.1
Bismuth	mg/Kg	0.13	0.16	0.22
Boron	mg/Kg	2	<3	5
Cadmium	mg/Kg	0.2	0.6	0.24
Calcium	mg/Kg	12,000	8,200	11,000
Cerium	mg/Kg	33	52	41
Cesium	mg/Kg	7	7.5	7.9
Chromium	mg/Kg	180	210	300
Cobalt	mg/Kg	3.7	8	8.2
Copper	mg/Kg	60	60	77
Gallium	mg/Kg	18	18	21
Germanium	mg/Kg	<0.4	<2	<0.5
Hafnium	mg/Kg	2.5	5.1	2.7
Indium	mg/Kg	<0.01	0.06	0.05
Iron	mg/Kg	16,000	20,000	23,000
Lanthanum	mg/Kg	16	25	20
Lead	mg/Kg	15	15	26
Lithium	mg/Kg	56	38	35
Magnesium	mg/Kg	6,000	3,800	5,000
Manganese	mg/Kg	380	380	450
Mercury	mg/Kg	0.7	1	2
Molybdenum	mg/Kg	2.4	7.1	14
Nickle	mg/Kg	21	70	170

Table H-2: Final Plant Tailings Solids Analysis of the Pre-Feasibility, Phase 1 Feasibility, and Phase 2 Feasibility Pilot Tests

Parameter	Unit	Feasibility Pilot (Phase 2) Final Tailings Filtrate 2007	Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007	Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006
Niobium	mg/Kg	6.7	5.6	4
Potassium	mg/Kg	23,000	23,000	22,000
Rhenium	mg/Kg	<0.02	<0.02	0.04
Rubidium	mg/Kg	98	140	130
Selenium	mg/Kg	<0.7	1	<1
Silicon	mg/Kg	309,000	330,000	-
Silver	mg/Kg	0.68	0.95	1.1
Sodium	mg/Kg	2,600	1,900	1,500
Strontium	mg/Kg	98	62	64
Tantalum	mg/Kg	0.72	0.71	0.86
Tellurium	mg/Kg	<0.4	<0.4	<0.4
Thallium	mg/Kg	0.9	0.9	1
Thorium	mg/Kg	11	23	10
Tin	mg/Kg	3.1	12	3
Titanium	mg/Kg	1,000	790	390
Tungsten	mg/Kg	5.8	12	6
Uranium	mg/Kg	2.7	2.7	2.7
Vanadium	mg/Kg	49	42	46
Ytterbium	mg/Kg	8.4	10	8.6
Zinc	mg/Kg	100	96	66
Zirconium	mg/Kg	-	71	44

Source: SRK 2012b, Table 4-2.

Table H-3: Final Plant Tailings Liquor - Major Components Analysis

Parameter	Unit	AWQC	Feasibility Pilot (Phase 2) Final Tailings Filtrate Oct 2007	Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007	Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006
Total Suspended Solids	mg/L		1	10	7
Total Dissolved Solids	mg/L	500 <sup>1</sup>	3,850	6,950	6,070
pH	Units	6.5-8.5 <sup>1</sup>	7.62	7.69	7.63
Alkalinity	mg/L as CaCO <sub>3</sub>	20 (min) <sup>2</sup>	44	47	52
Conductivity	µS/cm		3,860	5,970	5,390
Carbonate	mg/L as CaCO <sub>3</sub>		<2	<2	<2
Bicarbonate	mg/L as CaCO <sub>3</sub>		44	47	52
Hydroxide	mg/L as CaCO <sub>3</sub>		<0.6	<2	<2
Fluoride	mg/L	1 <sup>2e</sup>	0.91	0.5	0.77
Sulfate	mg/L	250 <sup>1</sup>	2,500	4,600	4,000
Nitrite	as N mg/L	1 <sup>2d</sup>	<0.6	<0.6	<0.6
Nitrate	as N mg/L	10 <sup>2d</sup>	<0.5	<0.5	<0.5
Ammonia	as N mg/L	0.18 <sup>2g</sup>	9.6	21	32.6
Cyanide Speciation					
Total Cyanide	µg/L		--	110	40
WAD Cyanide	µg/L	5.2 <sup>2b</sup>	--	80	<10
Free Cyanide	µg/L	5.2 <sup>2b</sup>	--	80	<20
Cyanate	µg/L		--	17,000	27,000
Thiocyanate	µg/L		--	2,100	8,000

Notes: -- Shaded values exceed applicable water quality criteria (AWQC).

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L; otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.

Source: SRK 2012b, Table 5-3.



Table H-4: Final Plant Tailings Liquor - Metals Analysis

Parameter	Unit	AWQC	Feasibility Pilot (Phase 2) Final Tailings Filtrate Oct 2007		Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007		Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006	
			Total	Dissolved	Total	Dissolved	Total	Dissolved
Major Constituents								
Calcium	mg/L	--	449	500	427	437	531	516
Magnesium	mg/L	--	150	160	820	833	682	659
Potassium	mg/L	--	40.4	45.3	63.8	62.5	50.1	48.7
Silicon	mg/L	--	2.34	2.56	3.07	2.92	--	--
Sodium	mg/L	--	376	275	93	95.9	120	116
Strontium	mg/L	--	2.63	2.34	3.83	3.69	2.46	2.54
Metals								
Aluminum	µg/L	750 <sup>2b</sup>	20	10	32.4	4.6	60	10
Antimony	µg/L	6 <sup>2d</sup>	45.9	44.9	31.9	34.3	38.6	34.1
Arsenic	µg/L	10 <sup>2d</sup>	1110	1090	467	483	454	432
Barium	µg/L	2,000 <sup>2d</sup>	22.9	22.4	27.8	25.6	23.1	22.7
Beryllium	µg/L	4 <sup>2d</sup>	<0.02	<0.02	<0.04	<0.04	<0.04	<0.04
Bismuth	µg/L	--	<0.01	<0.01	<0.02	<0.02	--	--
Boron	µg/L	750 <sup>2e</sup>	198	190	1170	1310	428	445
Cadmium	µg/L	0.64 <sup>2a,b</sup>	0.242	0.241	0.11	0.18	0.39	0.42
Cerium	µg/L	--	<0.07	<0.07	<0.09	<0.09	0.12	<0.09
Cesium	µg/L	--	<0.4	<0.4	5.2	5.72	5.23	4.7
Chromium, total	µg/L	100 <sup>2e</sup>	3.9	3.5	1.4	1	1.5	1.8
Cobalt	µg/L	50 <sup>2e</sup>	6.44	7.2	114	141	25.1	26.6
Copper	µg/L	29 <sup>2a,b</sup>	7.7	7.2	115	135	102	116
Gallium	µg/L	--	<0.01	0.11	0.33	0.33	1.04	1.1
Germanium	µg/L	--	0.27	0.25	0.5	1.7	<0.1	0.9
Hafnium	µg/L	---	0.548	0.05	0.22	0.07	1.03	0.64
Indium	µg/L	--	<0.01	<0.01	<0.04	<0.04	<0.04	0.1
Iron	µg/L	1,000 <sup>2b</sup>	270	170	200	50	190	<10
Lanthanum	µg/L	--	<0.04	<0.04	0.07	0.04	0.08	0.07
Lead	µg/L	11 <sup>2a,b</sup>	1	0.3	3.02	0.48	0.57	<0.02
Lithium	µg/L	2,500 <sup>2e</sup>	<2	5	16	16	747	743
Manganese	µg/L	50 <sup>2f</sup>	676	677	18,100	18,400	15,700	13,200

Table H-4: Final Plant Tailings Liquor - Metals Analysis

Parameter	Unit	AWQC	Feasibility Pilot (Phase 2) Final Tailings Filtrate Oct 2007		Feasibility Pilot (Phase 1) Final Tailings Filtrate Feb 2007		Pre-Feasibility Pilot Final Tailings Filtrate Oct 2006	
			Total	Dissolved	Total	Dissolved	Total	Dissolved
Molybdenum	µg/L	10 <sup>2e</sup>	78.1	73.6	106	114	302	259
Nickel	µg/L	100 <sup>2d</sup>	20.8	12.4	57.4	64.1	47.7	56.7
Niobium	µg/L	--	0.02	<0.001	<0.1	<0.1	0.6	<0.1
Rhenium	µg/L	--	<0.2	<0.2	0.12	0.18	0.46	0.46
Rubidium	µg/L	--	29	28.8	119	130	185	103
Selenium	µg/L	4.6 <sup>2b</sup>	14	16	42	44	28	33
Silver	µg/L	34.9 <sup>2a,b</sup>	0.03	<0.01	0.56	0.55	0.42	0.27
Tantalum	µg/L	--	0.02	<0.001	<0.03	<0.03	0.24	<0.03
Tellurium	µg/L	-	0.03	<0.03	<0.4	<0.4	<0.4	<0.4
Thallium	µg/L	1.7 <sup>2f</sup>	0.136	0.147	0.5	0.5	-	-
Thorium	µg/L	-	2.82	0.038	2.2	1.2	0.2	0.2
Tin	µg/L	--	0.11	0.15	1	0.8	--	--
Titanium	µg/L	-	0.6	0.4	1.4	69.6	0.9	1.1
Tungsten	µg/L	-	1.61	1.54	0.35	0.23	-	-
Uranium	µg/L	-	3.81	3.74	0.4	0.43	1.69	0.80
Vanadium	µg/L	100 <sup>2e</sup>	0.47	0.47	0.63	0.5	0.35	0.41
Ytterbium	µg/L	-	0.029	0.023	0.198	0.11	0.089	0.034
Zinc	µg/L	379 <sup>2a,c</sup>	11	23	15	15.9	42.1	15.1
Zirconium	µg/L	-	0.59	0.18	3.61	0.11	2.22	0.60
Mercury	ng/L	12 <sup>2b</sup>	40	20	28	--	24,200	--

Notes:--Shaded values exceed applicable water quality criteria (AWQC).

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L; otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.

Source: SRK 2012b, Table 5-4.

## 1.3 Open Pit and Pit Lake

The resource to be mined is located in two main areas, ACMA and Lewis, which would be mined as two open pits (SRK 2012a). As ore and waste rock are mined, the open pits would grow and partially coalesce later in the mine life (Figure 2.3-2, Chapter 2, Alternatives). The ultimate pit footprint is planned to be approximately 2.2 miles long by 1 mile wide. The ultimate depths of the Lewis and ACMA pits would be 1,653 feet and 1,850 feet, respectively, from the upper highwall to the final pit bottom (SRK 2012a).

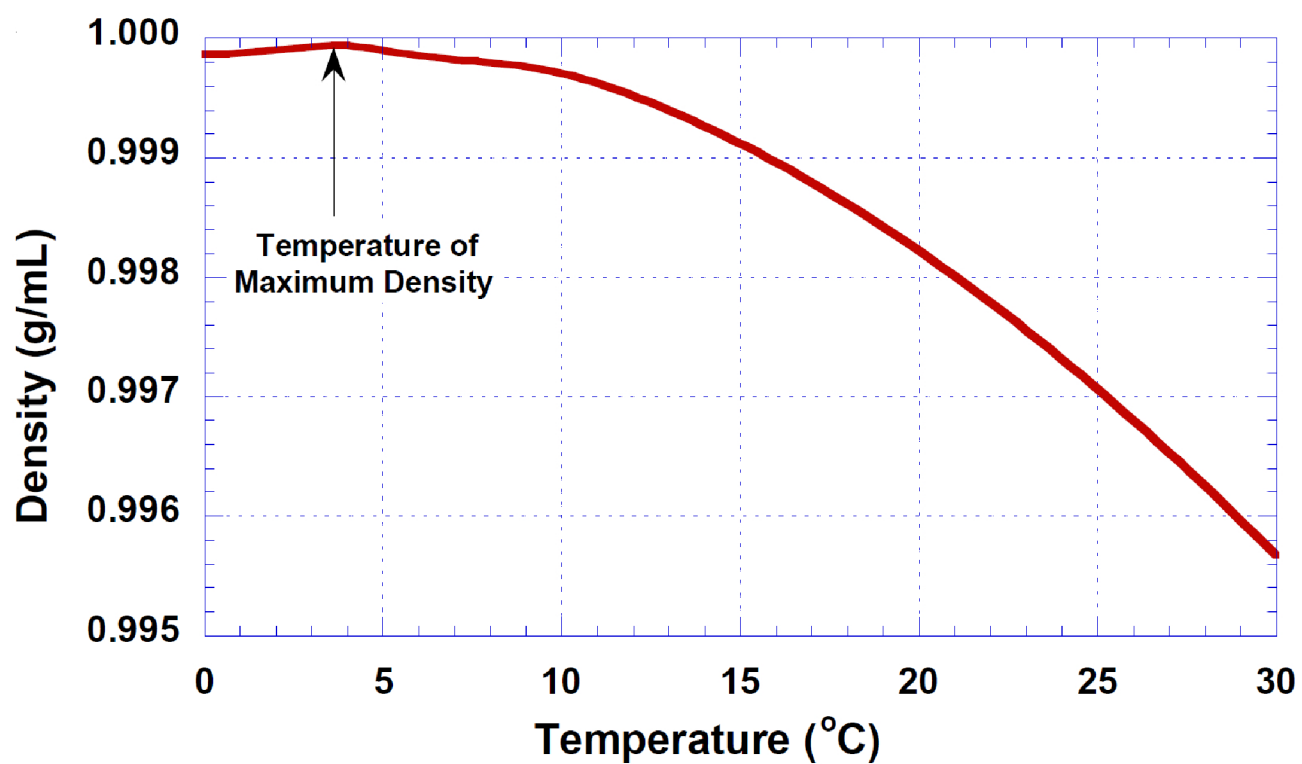
In the mining process, rock that would eventually become ore or waste rock would be progressively exposed to oxidizing atmospheric conditions. These newly exposed rocks include all the NAG and PAG rock categories discussed previously in the WRF section. Runoff from the pit walls and groundwater seeping into the pit would likely react with the rocks and is thus considered contact water. This water would be pumped out of the pit during construction and operations, but would be allowed to remain in the pit after closure (SRK 2012b).

A major component of the post-closure contact water management strategy is also to pump low quality water from various other mine sources to a deep layer of the pit lake. This would be done in order to form a permanently stratified pit lake with high total dissolved solids (TDS), low-quality, denser water near the bottom, and lower-metal-content, lower-TDS water at the surface (Lorax 2012a, 2015). The surface water would then require less treatment before discharge. It is estimated that approximately 53 years after mine closure the pit will have filled to near its controlled discharge elevation of 316 feet above mean sea level (AMSL), at which time water will be treated and discharged to Crooked Creek. The controlled discharge elevation is planned to be approximately 33 feet below the spillway elevation of 349 feet AMSL.

### 1.3.1 Lake Stratification Processes

The behavior of lake water with regard to stratification has important implications for pit surface water quality in the post-closure period. The existence of stratified pit lakes has been widely documented (e.g., Filipek et al. 2004; Castendyk and Early 2009). The process of vertical stratification in lakes is due to variations in the density of the water at different depths, and may be seasonal or permanent. If waters from different sources with different densities enter a lake, they can and will adjust themselves vertically until they reach a stable—or stratified—density configuration, with the highest density water at depth and the lowest density at the surface.

The density of water is a function of both its temperature and salinity, or total dissolved solids (TDS) content. Freshwater is densest at a temperature of about 40°F (4°C on Figure H-1). Above this temperature, the density decreases with increasing temperature. Below this temperature, the density decreases with decreasing temperature until it reaches its freezing point. At a given temperature, water density increases with increasing TDS. As its TDS increases, the temperature of maximum density of water also decreases.



Data Source: Lorax 2012



DONLIN GOLD  
PROJECT EIS



### WATER DENSITY AS A FUNCTION OF TEMPERATURE

NOVEMBER 2015

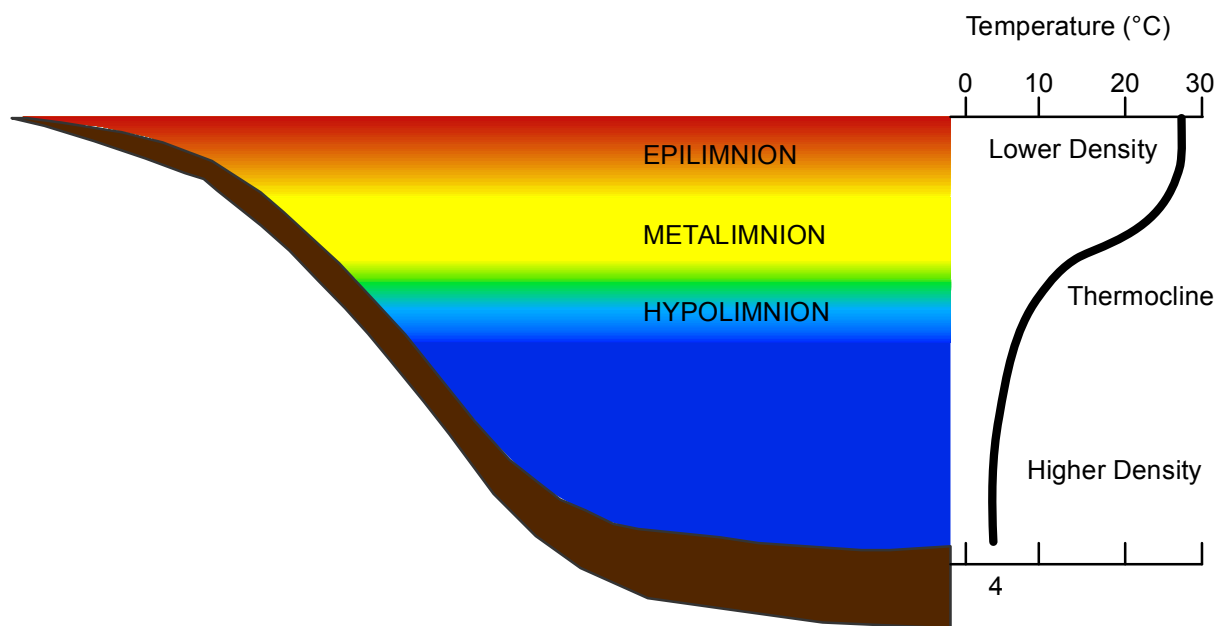
APPENDIX H FIGURE 1

### 1.3.2 Seasonal Effects on Stratification

Thermally-induced seasonal density stratification is the norm in temperate to high latitude lakes of uniform chemistry (i.e., uniform TDS), and is due to the following processes.

- As air temperature and solar radiation increase in spring and summer, the surface water heats from above. This heating causes the density of the surface layer to decrease. The lake then has a surface layer (*epilimnion*) of uniform lower density and higher temperature, and an underlying layer (*hypolimnion*) of higher density and lower temperature. These layers are separated by a zone called the *thermocline* (or *metalimnion*) in which the temperature decreases rapidly with depth (Figure H-2). Above the thermocline, the surface water is mixed by wind and is typically in equilibrium with atmospheric oxygen. The epilimnion is typically less than about 20 to 30 feet deep, because wind-induced mixing in mid- to high-latitude pit lakes seldom reaches beyond this depth. Below the thermocline, oxygen may gradually become depleted by oxidation of organic matter that falls into the hypolimnion from the surface.
- At some point in the late autumn or early winter, the surface water temperature drops below that of the underlying water and reaches a point at which the surface water density is greater than that of the underlying water, which is an unstable situation. The surface water sinks until it reaches the level of its new density. Eventually, the entire water column may overturn, depending on the temperature structure of the lower layer and the amount of cooling at the surface. Overturn through the water column could take less than a day or occur over several weeks, and causes mixing which replenishes the oxygen throughout the depth of overturn, potentially to the bottom of the lake.
- When ice forms in early winter, the water below the ice may gradually lose its oxygen by the same processes that occur in the lower layer in summer. Below the ice, the water may become temperature-stratified with 40°F water at the bottom or it could remain well-mixed due to heating from the sides and bottom of the pit. Which process occurs depends on the relative temperatures of the air, water, and ground and the thermal conductivity of the ground.
- In spring, the air temperature increases. Ice gradually melts and the water temperature increases from the surface downward, as well as from the bottom up. When the surface water temperature reaches 40°F, the lake may again overturn and re-oxygenate due to the denser surface water.

## Thermal Stratification



Data Source: Herbert 2012



DONLIN GOLD  
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THERMAL STRATIFICATION DURING  
SUMMER IN FRESHWATER LAKES

NOVEMBER 2015

APPENDIX H FIGURE 2

### 1.3.3 Chemical Effects on Stratification

This seasonal cycle is based on a pit lake with either no TDS or constant TDS with depth. Long-term (multi-year) or permanent density stratification can occur due to the following processes.

- A lake can develop a large vertical variation in TDS due to differences in the TDS of various source waters to the lake and/or to processes in the lake that increase the TDS, and thus the density, of the deeper water. For example, if the lake contains enough organic matter to deplete oxygen in the hypolimnion during the summer, any ferric hydroxide that precipitates at the surface and falls to the lake bottom may become reduced and dissolved in the anoxic bottom water, raising the TDS content and the density of the bottom water.
- Typically, a chemically stratified lake (i.e. one with vertical variations in TDS) has an upper epilimnion layer of lower TDS water overlying a hypolimnion layer of higher TDS water. The two layers are separated by a zone called the *pycnocline* in which the TDS and the water density increase rapidly with depth. If the bottom layer is sufficiently deep (well below the depth of summer wind mixing), a seasonal middle layer (*metalimnion*) may form below the summer thermocline and above the denser hypolimnion. Overturn in the fall/winter usually occurs throughout the metalimnion, but not the hypolimnion. Thus, once the hypolimnion becomes anoxic, it may remain so and may continuously dissolve any ferric hydroxide precipitates falling into it from above and release any metals sorbed onto the ferric hydroxide. This process further increases the TDS of the hypolimnion and strengthens the density gradient between it and the overlying layer, perpetuating the stratification. The larger the density difference between vertical layers of the lake, the more stable the stratification and the less prone the lake is to overturn and mix.

### 1.3.4 Physical Effects on Stratification

Physical processes such as precipitation, evaporation, ice formation, melting, wind, and molecular diffusion can also increase or decrease vertical density differences.

- For example, if precipitation, spring snowmelt, or runoff have lower TDS than the lake-water TDS, their addition could induce stratification near the lake surface, even when no temperature differences exist.
- Ice formation excludes dissolved salts and causes the water underlying the ice to become more concentrated. The underlying unfrozen water also may become reducing over the winter due to the lack of exposure to oxygen under ice cover. If a substantial thickness of ice forms in winter in such a lake (on the order of 5 feet estimated for the ACMA pit lake [Lorax 2012b]) then the initial melt water from ice and overlying snow could be more dilute than the water underlying the previous ice. If water to be treated and discharged is pumped from the pit lake surface soon after ice melts, then it may remove only the dilute ice-melt water and concentrate the remaining water. Later in summer, the surface water may then become even more concentrated because runoff from the pit walls forms a larger portion of the water. If each spring the water pumped and treated consists mainly of ice melt and that process continues year after year, the remaining surface water may become increasingly concentrated over time, never reaching a “steady state.” Thus, in order to maintain the surface water concentrations within a relatively narrow band of water quality over the long term, it may be necessary to seasonally adjust the

depth from which water is pumped, for example, to pump water from below the ice-melt layer each spring. Countering density stratification are the slow processes of thermal and molecular diffusion, which tend to homogenize the water in terms of temperature and salinity. Thermal diffusivity in water is on the order of  $10^{-5}$  m<sup>2</sup>/sec, or about a m<sup>2</sup>/day; while molecular diffusivity in water is several orders of magnitude slower.

## 2. Construction

Construction at the mine site is planned to take place over a 3-year period. The American Creek drainage into the CWDs, pit dewatering, overburden stockpiles, and TSF (Anaconda Creek runoff) are the primary geochemical components of the mine site that could potentially impact surface water quality during the construction phase. Management objectives during construction include minimizing build-up of contact water in the Lower CWD and eliminating the need to store water in the TSF until immediately before mine start-up. A detailed discussion of water treatment objectives during construction is given in Section 3.7.3.2.2, Water Quality of the EIS.

### 2.1 Overburden Stockpiles

Overburden removed from the pit and TSF that is planned for later use in reclamation would be stored in the overburden stockpiles located near Crooked Creek (EIS Figures 2.3-6 and 2.3-7). The stockpiles would be protected from erosion and sedimentation through Best Management Practices (BMPs) and design features such as berms, diversion channels, and sedimentation ponds (EIS Section 3.2.3.2.3, Soils). Runoff from the stockpiles would be directed toward sediment ponds. Materials in the North Overburden Stockpile (NOB) are not considered to pose an ARD or M/L risk, so runoff and seepage are considered suitable for discharge from the sediment ponds. The South Overburden Stockpile (SOB) would contain terrace gravel and colluvium from the open pit. As described above (Infrastructure and Processes, WRF), there is the possibility for arsenic and other metals leaching, as well as ARD, from the mineralized zone of the open pits (BGC 2011g). Accordingly, runoff collected the SOB sediment pond is planned to be pumped to the Lower CWD (SRK 2012b). Three overburden stockpiles are also planned to be located downstream of the TSF.

### 2.2 Waste Rock Facility

Details of the American Creek WRF construction are given in Section 2.3.2.1.9, Chapter 2, Alternatives, of the EIS. The foundation is planned to be built of coarse waste rock to allow drainage from the facility as well as discharging springs in the valley bottoms. The NAG 1-4 rock would be blended with PAG 5 rock in the interior of the WRF. The last 80 feet of the dump crest of any lift would be limited to only NAG 1-4 rock to minimize the potential for ARD formation (SRK 2012e). The Lower and Upper CWD ponds are planned to be built in American Creek for the purpose of managing runoff from the WRF and pit and preventing mine contact water from release to the environment (SRK 2012b). NAG waste rock with metal leaching potential could be used for construction of the Lower CWD. Runoff and seepage from the Lower CWD would be collected either in the ACMA pit dewatering system, or at a proposed ore stockpile berm designed to minimize surface runoff to the pit. The ACMA pit would intersect American Creek downstream of the dam during construction, so that runoff and seepage from the Lower CWD would not migrate off site.



Seepage from the WRF is planned to be contained by the Lower CWD and monitored quarterly (SRK 2012c). The water quality of seepage from both the NAG and PAG portions of the WRF during construction could exceed AWQS for certain constituents. This water would be stored during construction for later use as process water during operations or treated, as needed, by using the AWT.

## 2.3 Low-Grade Ore Stockpile

The low-grade ore stockpile is the area set aside to hold rock of too low grade to process. It is to be located between the Lower CWD and the ACMA pit (EIS Figure 2.3-6, Chapter 2, Alternatives). During the early years of construction, a berm is planned to be constructed on American Creek, immediately downstream of the low-grade ore stockpile area to collect runoff downgradient from the Lower CWD. Contact water collected above the berm would be pumped to the Lower CWD. Any water overtopping the berm would flow to the ACMA pit and be collected by the pit dewatering system.

## 2.4 Tailings Storage Facility

The TSF is planned to be a fully-lined facility constructed in six stages over the 27.5-year mine life. A seepage recovery system (SRS) is planned immediately downstream of the main tailings dam, which would collect groundwater and any seepage from the lined TSF. This water would be pumped to the TSF or treated using AWT, as needed, for water management.

Reclaim water from the tailings pond would be recycled back to the process facility from a floating barge via a pipeline (SRK 2012a). Some PAG 5, 6, and 7 rock is planned to be placed in lined portions of the TSF for use in construction of the causeway to the reclaim barge (SRK 2012b). Using PAG rock for the causeway could result in formation of ARD, which would drain into the TSF. Two freshwater diversion dams upstream of the TSF in Anaconda Creek are planned to be maintained during construction and the first 3 years of operations. During construction, these dams would divert non-contact water around the TSF and facilitate construction of the facility (SRK 2012a). In year 3 of construction, the dams would be decommissioned to allow for additional tailings storage. No tailings would be generated until the mine begins operations. On the north and south sides of the TSF, freshwater diversions would continue to be constructed in stages until Year 17.

## 2.5 Open Pit

It is anticipated that only non-contact water perimeter wells, but not in-pit (contact water) dewatering wells, would be required during the construction period (SRK 2012b). Water collected from perimeter wells is predicted to exceed AWQC for several constituents including dissolved antimony, arsenic, iron, and manganese, and total concentrations of aluminum, antimony, arsenic, copper, iron, lead, and manganese (BGC 2014b; Hatch 2015). Accordingly, during construction, the water is planned to be treated using the AWT. A water treatment plant (WTP) is planned to treat this water, as necessary, before being discharged to Crooked Creek (SGS 2012). A more detailed discussion is provided in Section 3.7.3.2.2, Water Quality.

## 3. Operations and Maintenance

Alternative 2 would involve operation of mine site facilities located in the American Creek and Anaconda Creek drainages. These include the overburden stockpiles, WRF, low-grade ore

stockpile, the CWDs, TSF and associated SRS, and the mine pit. A set of operational rules has been designed to maintain maximum operational pond volumes of 811 acre-feet for the Lower CWD and 2,432 acre-feet for the Upper CWD (BGC 2015f). The rules determine which combination of water sources would be treated using the AWT at the WTP. The potential sources include: the pit perimeter and in-pit dewatering wells, inflows to the SRS, CWD water, and TSF water. Each of these sources is discussed in the following sections, except the pit perimeter and in-pit dewatering wells, which are discussed in Section 3.7.3.2.2, Water Quality.

### 3.1 Overburden Stockpiles

As discussed previously, the materials in the SOB stockpile have the potential to leach metals. Therefore, seepage and surface runoff from the SOB is planned to be captured and pumped to the Lower CWD for use in process or for treatment and discharge, as needed. In addition, the stockpile will be progressively reclaimed to minimize infiltration and entrainment. However, the potential exists for seepage underground to flow toward Crooked Creek. This issue is discussed in more detail in EIS Section 3.6, Groundwater Hydrology and potential mitigation measures are discussed in Chapter 5 of the EIS, Impact Avoidance, Minimization, and Mitigation. Over the course of mine operations, all materials placed in the SOB will eventually be moved to the WRF and placed as waste or as internal capping material for the PAG cells (SRK 2012b).

### 3.2 Waste Rock Facility

During project operations, the WRF is planned to be progressively reclaimed by placing a cover of a minimum of 14 inches of growth medium over a minimum 12 inches of lower permeability terrace gravel and/or colluvium to reduce infiltration and seepage. The seepage from the WRF is planned to be collected and used as process water.

Predicted water quality is given in Table H-2 for selected years of mining for the NAG WRF and Year 8 for the isolated PAG cells. It should be noted that all predictions of future water quality are estimates based on a number of assumptions, as discussed in SRK 2007, and likely represent order-of-magnitude approximations. If the NAG and PAG 5 rock are well blended within the WRF, then the pH is predicted to remain circumneutral throughout the estimated mine life with a sulfate concentration of approximately 2,000 mg/L. If the blending is incomplete, then the pH is predicted to decrease near the end of mine life to about pH 3.2, with sulfate concentrations increasing to about 18,000 mg/L. In either case, a number of constituents are predicted to exceed AWQC throughout the mine life. For example, in drainage from the NAG WRF, arsenic concentrations are predicted to be approximately 26,000 µg/L, antimony 2,400 µg/L, selenium about 150 µg/L, and mercury 80 ng/L. The PAG cells could eventually have seepage with pH as low as 1.8, manganese concentrations of approximately 290,000 µg/L; zinc, approximately 350,000 µg/L; and selenium, approximately 2,700 µg/L. Surface and groundwater potentially containing seepage from this area would be intercepted and pumped back into the Lower CWD.

Table H-5: Pore-water Quality for NAG and PAG Portions of WRF during Operations

WRF Facility Time	Units	AWQS	Well Mixed NAG Year 8	Poorly Mixed NAG Year 8	Well Mixed NAG Year 19	Poorly Mixed NAG Year 19	Well Mixed NAG Year 26	Poorly Mixed NAG Year 26	Well Mixed PAG Year 8	Poorly Mixed PAG Year 8
Major Constituents										
pH	Units	6.5-8.5 <sup>1</sup>	7.7	7.6	7.7	7.6	7.7	3.2	7.5	1.8
Sulfate	mg/L	250 <sup>1</sup>	2,000	2,600	2,000	2,600	2,000	18,000	39,000	58,000
Nitrate	mg/L as N	10 <sup>2d</sup>	2.4	2.4	0.0038	0.0038	0	0	2.4	2.4
Nitrite	mg/L as N	1 <sup>2d</sup>	0.0078	0.0078	0.000012	0.000012	0	0	0.0078	0.0078
Ammonia	mg/L as N	0.18 <sup>2g</sup>	0.26	0.26	0.00042	0.00042	0	0	0.26	0.26
Calcium	mg/L	-	710	660	710	660	710	490	410	480
Magnesium	mg/L	-	64	260	64	270	64	1,700	9,400	81
Potassium	mg/L	-	27	27	27	27	27	<1	27	150
Acidity	µg/L	-	170	170	170	170	170	19,000,000	170	60,000,000
Alkalinity	mg/L	20 (min) <sup>2b</sup>	24	19	24	19	25	26	25	0
Metals										
Aluminum	µg/L	87/750 <sup>2a,b</sup>	29	29	29	29	29	210,000	29	7,800,000
Antimony	µg/L	6 <sup>2d</sup>	2,400	2,400	2,400	2,400	2,400	2,200	2,400	2,300
Arsenic	µg/L	10 <sup>2d</sup>	26,000	23,000	26,000	23,000	26,000	26,000	26,000	27,000
Barium	µg/L	2,000 <sup>2d</sup>	4.7	4.7	4.7	4.5	4.7	3.8	3.4	3.7
Beryllium	µg/L	4 <sup>2d</sup>	0.4	0.4	0.4	0.4	0.4	40	0.4	16
Cadmium	µg/L	0.64 <sup>2a,b</sup>	0.5	0.5	0.5	0.5	0.5	36	0.5	15
Chromium	µg/L	100 <sup>2e</sup>	31	31	31	31	31	85	31	53
Cobalt	µg/L	50 <sup>2e</sup>	87	87	87	87	87	570	87	280
Copper	µg/L	29 <sup>2a,b</sup>	25	29	25	29	25	450	110	55,000

Table H-5: Pore-water Quality for NAG and PAG Portions of WRF during Operations

WRF Facility Time	Units	AWQS	Well Mixed NAG Year 8	Poorly Mixed NAG Year 8	Well Mixed NAG Year 19	Poorly Mixed NAG Year 19	Well Mixed NAG Year 26	Poorly Mixed NAG Year 26	Well Mixed PAG Year 8	Poorly Mixed PAG Year 8
Iron	µg/L	1,000 <sup>2b</sup>	2.1	2.1	2.1	2.1	2.1	3,700,000	2.4	2,300,000
Lead	µg/L	11 <sup>2a,b</sup>	14	14	14	14	14	450	7,400	480
Manganese	µg/L	50 <sup>2f</sup>	8,800	9,300	8,800	9,400	8,700	13,000	80,000	290,000
Molybdenum	µg/L	10 <sup>2e</sup>	820	820	820	820	820	760	820	800
Nickel	µg/L	100 <sup>2a,d</sup>	390	390	390	390	390	870	390	580
Selenium	µg/L	4.6 <sup>2b</sup>	130	180	130	180	140	170	2,700	150 <sup>3</sup>
Silver	µg/L	-	1.0	1.0	1.0	1.0	1.0	0.97	1.0	0.99
Thallium	µg/L	1.7 <sup>2f</sup>	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0
Zinc	µg/L	379 <sup>2a,c</sup>	110	110	110	110	110	31,000	390,000	340,000
Mercury	ng/L	12 <sup>2b</sup>	77	77	77	77	77	82	77	79

Notes:

All concentrations are dissolved and should be used as the average annual.

Shaded cells exceed most stringent water quality standard:

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L; otherwise 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.

3 Lorax 2015 suggests selenium concentrations in PAG drainage could eventually reach 80,000 µg/L or more (Table 2-1).

Source: SRK 2007, Table 2-18.

During operations, the WRF would be inspected and monitored as follows (SRK 2012e, c):

- Each area of the WRF that is undergoing active development or concurrent reclamation is planned to be visually inspected weekly, and non-active areas inspected monthly;
- Complete annual inspections would be carried out for reclaimed portions of the WRF until closure, and the results recorded in a document storage system developed for the site;
- The toe of the WRF would be checked for seepage on a monthly basis, and as soon as practicable after major precipitation events. If seepage is observed, the location and flow rate would be recorded, and a sample collected for water quality analysis; and the seepage would be pumped to the Lower CWD.

The predictions for the isolated PAG cell pore water in Table H-1 (mixed PAG) were based on an earlier waste rock management plan that assumed PAG 6 and PAG 7 are both included in the PAG dump (PAG 7 is now planned to go to the pit). Based on modeling, PAG 6 rock is predicted to produce ARD in less than roughly 10 years (SRK 2007 and Table 3-3). Thus, "Well Mixed PAG Y8" in Table H-1 is likely to be similar to PAG 6 seepage during the first decade of operations. Thereafter, with only PAG 6 rock, oxidation is predicted to produce acidic drainage more slowly, and the resultant seepage may have somewhat lower concentrations than shown for poorly mixed PAG at Year 8 in Table H-1. Accordingly, the quality of water from the PAG 6 seepage is predicted to degrade over time during operations. Selenium concentrations, in particular, are expected to increase over time to levels as much as two orders of magnitude greater than shown in Table H-5. (see Lorax 2015, Table 2-1). The intermediate cover of terrace gravel and colluvium within a year of placement is predicted to reduce long-term percolation rates by about 36 percent from the rates predicted for bare PAG waste rock (O'Kane Consultants Inc. 2009). This water is planned to report to the Lower CWD.

### 3.3 Low-Grade Ore Stockpile

The low-grade ore stockpile is the area set aside to hold PAG 7 rock of too low grade to process as ore at the time of mining. The PAG 7 rock has the potential to generate acid over a relatively short period (possibly within a decade). The drainage from this rock would be collected by the berm between it and the pit and pumped to the Lower CWD, where it would be co-mingled with other contact water. Any overflow from the berm would drain to the pit and be collected by the pit dewatering system.

### 3.4 Lower CWD

The Lower CWD is planned to hold runoff and seepage from several sources (BGC 2014b, 2015f). The major flows include surface water from the pit and the low-grade ore stockpile (estimated at 999 gpm during operations for average precipitation) and runoff from undisturbed areas of American Creek watershed (703 gpm). Lesser inflows include the WRF (242 gpm seepage and 172 gpm surface flow) and the SOB sediment pond (92 gpm). This water would be stored during construction for later use as process water during operations, as needed, and would continue to receive water throughout the life of the mine. It would be monitored quarterly (SRK 2012c) and sent to the Upper CWD, then on to the WTP for treatment, as needed.

The water quality of the Lower CWD would likely be variable, due to the variation in the input sources, both seasonally and over time. The quality would be expected to decrease over time as the PAG rock in the low-grade ore stockpile, the PAG 6 cells of the WRF, and the exposed surfaces of the pit weather. Order-of-magnitude estimates of the water quality of the Lower CWD are given in Table H-6. These estimates were developed using two approaches.

The first approach consisted of mixing the predicted water chemistries of the various water sources to the pond (from SRK 2007, 2011; Lorax 2012a; and ARCADIS 2012b) at their annual average relative flows, as given by BGC (2014b, 2015f), using PHREEQC (PHREEQC is a public domain geochemical computer code developed by the U.S. Geological Survey, Parkhurst and Appelo 2013). The code allows both conservative mixing, which adjusts the final pH based on the acidities/alkalinities of the input waters, and mixing with mineral precipitation, when the mineral is saturated and forming in the mixture. Whether and which minerals are allowed to precipitate is at the user's discretion because precipitation of many minerals is kinetically hindered under certain environmental conditions. This type of modeling is based on known thermodynamic data and is the standard method of estimating geochemical mixing and mineral precipitation across a spectrum of aqueous environments.

Undisturbed American Creek watershed and SOB flows were approximated by the average surface water concentrations for Category 2 Locations--background streams in mineralized area (EIS Table 3.7-3, Section 3.7, Water Quality). Surface water from the pit and the low-grade ore stockpile was developed assuming the pit walls have the average ratio of different rock types, as shown in EIS Figure 3.7-14 (EIS Section 3.7, Water Quality), Tonnage-weighted Annual Average NP/AP for Waste Rock Categories.

Two different scenarios were developed for the PAG rock leachate from the pit walls and low-grade ore stockpile. The first (Pit wall avg PAG) assumes that the PAG rocks produce drainage that is the average of exhausted PAG and peak PAG used in modeling the closure pit lake. (These chemistries are discussed in detail in Section 4.4.2 of this appendix (Pit Lake – Pit Lake Modeling). The second (Pit wall peak PAG) assumes that the PAG rocks are producing drainage at their peak rate.

The chemistry of seepage from rocks in the NAG WRF is predicted to remain relatively constant over time for the first 20 or so years of operations (SRK 2007). However, if the NAG and PAG 5 rocks are not well mixed, the PAG rocks may begin to produce higher-concentration, more acidic seepage by the end of mine life, based on the predictions in SRK 2007 for Year 26 (Table H-5). Accordingly, three scenarios were developed for the seepage chemistry from the NAG and PAG WRF areas. During most years of Operations, seepages from the NAG and PAG portions of the WRF were assumed to have concentrations ranging from those given for well mixed Year 8 to those given for poorly mixed Year 8 WRF seeps in Table H-5 (from SRK 2007). By the end of mine life, seepage from poorly mixed WRF is expected to degrade substantially. For this scenario, end-of-mine life seepage was assumed to be that of Year 26 poorly mixed NAG WRF seepage from Table H-5. The surface water runoff from the WRF is assumed to have the concentrations used in PitMod (Lorax 2012a, 2015). In half of the runs, no minerals were allowed to precipitate. In the other half, aluminum and iron sulfato-oxyhydroxide minerals were allowed to precipitate at saturation, assuming equilibrium with atmospheric oxygen and carbon dioxide. These secondary mineral phases would be the most common to form from the composition of these types of waters. If iron oxyhydroxide (ferrihydrite) precipitated, other constituents were allowed to adsorb onto the mineral surface.

Table H-6: Predicted Lower CWD Pond Concentrations

Source Assumptions <sup>3</sup>			PHREEQC Mix <sup>3</sup>										Water Treatment Design Basis <sup>8</sup>	
Pit Walls <sup>4</sup>			Avg PAG		Peak PAG		Avg PAG		Peak PAG		Peak PAG		50th	95th
WRF Seep <sup>5</sup>			Well mixed Yr 8		Well mixed Yr 8		Poorly mixed Yr 8		Poorly mixed Yr 8		Poorly mixed Yr 26		Percentile	Percentile
Precipitation / Adsorption <sup>5</sup>			No	Yes	No	Yes	No	Yes	No	Yes	No	Yes		
	Units	AWQC												
Major Constituents														
pH	S.U.	6.5-8.5 <sup>1</sup>	7.9	7.9	7.4	7.5	5.7	4.7	5.5	4.2	3.9	2.8	7.8	8.0
Calcium	mg/L		120	120	120	120	120	120	120	120	100	100	160	180
Magnesium	mg/L		57	57	69	69	55	55	68	68	290	290	19	25
Potassium	mg/L		21	21	21	21	21	19	21	21	18	18	21	27
Sodium	mg/L		21	21	24	24	23	23	26	26	26	26	12	27
Chloride	mg/L	230 <sup>2b</sup>	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.0	1.4
Fluoride	mg/L	1 <sup>2e</sup>	NR <sup>7</sup>	NR	NR	NR	NR	NR	NR	NR	NR	NR	0.18	0.19
Sulfate	mg/L	250 <sup>1</sup>	550	550	640	630	660	590	750	680	2,400	2,400	460	550
Total Dissolved Solids (est.)	mg/L	500 <sup>1</sup>	790	780	900	890	920	810	1,000	930	3,300	3,100	750	910
Metals														
Aluminum	µg/L	87/750 <sup>2a,b</sup>	3,600	21	7,200	8.1	23,000	2,000	27,000	6,000	49,000	49,000	64	144
Antimony	µg/L	6 <sup>2d</sup>	520	520	530	530	520	520	530	530	510	500	700	800
Arsenic	µg/L	10 <sup>2d</sup>	4,700	4,700	5,400	5,100	4,400	4,400	5,100	4,000	5,400	1,000	4,000	4,700
Barium	µg/L	2,000 <sup>2d</sup>	32	32	32	32	32	32	32	32	32	31	82	172
Beryllium	µg/L	4 <sup>2d</sup>	4.2	0.33	7.9	0.014	4.2	4.2	8.0	4.7	12	12	0.5	0.6
Boron	µg/L	750 <sup>2e</sup>	740	740	740	740	740	740	740	740	740	740	150	160
Cadmium	µg/L	0.64 <sup>2a,b</sup>	1.8	1.7	2.8	2.7	1.8	1.8	2.9	2.9	6.7	6.6	1	1
Chromium	µg/L	100 <sup>2d</sup>	21	21	26	26	21	21	26	26	32	31	20	21
Cobalt	µg/L	50 <sup>2e</sup>	49	49	80	79	50	50	81	81	130	130	50	51
Copper	µg/L	29 <sup>2a,b</sup>	84	7.8	160	3.5	220	220	300	300	340	340	8	8
Iron	µg/L	1,000 <sup>2b</sup>	2,400	0.22	4,400	0.58	8,200	39	10,000	1,100	410,000	210,000	230	470
Lead	µg/L	10.9 <sup>2a,b</sup>	30	2.3	32	0.79	12	12	15	14	61	61	70	80
Manganese	µg/L	50 <sup>2f</sup>	1,700	1,700	2,100	2,100	2,300	2,300	2,700	2,700	3,100	3,100	1,500	2,000
Molybdenum	µg/L	10 <sup>2e</sup>	150	150	150	150	150	150	150	140	140	140	160	200
Nickel	µg/L	100 <sup>2a,b</sup>	180	170	270	260	180	180	270	270	330	320	310	310
Selenium	µg/L	4.6 <sup>2b</sup>	99	99	110	110	98	98	100	100	100	100	200	220
Thallium	µg/L	1.7 <sup>2f</sup>	0.75	0.75	0.78	0.78	0.75	0.75	0.78	0.78	0.79	0.79	1	1



Table H-6: Predicted Lower CWD Pond Concentrations

Source Assumptions <sup>3</sup>			PHREEQC Mix <sup>3</sup>										Water Treatment Design Basis <sup>8</sup>	
Pit Walls <sup>4</sup>			Avg PAG		Peak PAG		Avg PAG		Peak PAG		Peak PAG		50th	95th
WRF Seep <sup>5</sup>			Well mixed Yr 8		Well mixed Yr 8		Poorly mixed Yr 8		Poorly mixed Yr 8		Poorly mixed Yr 26		Percentile	Percentile
Precipitation / Adsorption <sup>5</sup>			No	Yes	No	Yes	No	Yes	No	Yes	No	Yes		
Zinc	µg/L	379 <sup>2a,c</sup>	1,500	1,300	1,900	1,600	1,300	1,300	1,800	1,800	5,100	5,000	440	460
WAD Cyanide	µg/L	5.2 <sup>2b</sup>	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	4.3	5.0
Mercury	ng/L	12 <sup>2a,b</sup>	96	94	98	81	96	96	98	98	99	98	130	150
Minerals Precipitated <sup>6</sup>			Ferrihydrite		Ferrihydrite		K-Jarosite		Ferrihydrite		Ferrihydrite			
			Basaluminite		Basaluminite		Basaluminite		Jurbanite					
							Jurbanite							

Notes:

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L, otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms)

3 All chemistry calculations using PHREEQC assume (a) The relative flows areas given in Figure 4-3 of BGC 2015f; (b) Undisturbed American Creek watershed and SOB flows were approximated by the average surface water concentrations for Category 2 Locations--background streams in mineralized area (EIS Table 3.7-3); (c) The pit walls have the average ratio of different rock types, as shown in EIS Figure 3.7-14, Tonnage-weighted Annual Average NP/AP for Waste Rock Categories, and (d) The surface water drainage from the WRF has the concentrations used in PitMod.

4 For pit walls: Avg PAG assumes that the PAG rocks on the pit wall produce drainage that is the average of exhausted PAG and peak PAG used in modeling the pit lake; Peak PAG assumes that the PAG rocks are producing drainage at their peak rate.

5 For WRF Seeps, Well mixed Y8, Poorly mixed Y8, and Poorly mixed Y26 have the concentrations given in Table 3.7A-5, Pore-water quality for NAG portions of WRF during Operations (from SRK 2007, Table 2-18). All PAG seepage has the concentrations of Poorly mixed Y8 PAG seepage from the same table.

6 If No, no minerals are allowed to precipitate. If Yes, then aluminum and iron sulfato-hydroxide minerals are allowed to precipitate at saturation and other constituents are allowed to adsorb onto any iron oxyhydroxide mineral.

7 NR = Not reported in SRK 2007 or 2011

8 Hatch 2015



The results of the Lower CWD chemistry modeling suggest that several constituents would exceed the most stringent AWQC for all PHREEQC-modeled scenarios. These include sulfate, TDS, antimony, arsenic, cadmium, manganese, molybdenum, nickel, selenium, zinc, and mercury. Even though the WRF seepage is only about 11 percent of the total expected inflow to the Lower CWD, the quality of blending of NAG and PAG rocks in the WRF appears to have a substantial effect on the pH, certain metals (aluminum, beryllium, cobalt, copper, iron, and lead), and stored acidity (due to the dissolved iron and aluminum) of the water in the Lower CWD. The low pH environment caused by seepage from a poorly mixed WRF keeps most constituents in solution, even when iron and aluminum minerals are allowed to precipitate because adsorption of cationic metals onto precipitated iron oxyhydroxide (ferrihydrite) is inhibited at low pH. However, the oxyanion arsenic shows its greatest adsorption at the lowest pH, decreasing to less than a fifth of its non-adsorbed concentration (but still above AWQC, i.e. 1,000 µg/L adsorbed vs 5,400 µg/L non-adsorbed). In the circumneutral waters predicted to form assuming seepage from a well-mixed WRF, aluminum, beryllium, copper, iron, and lead exceed standards in both scenarios in which iron and aluminum minerals are not allowed to precipitate. When mineral precipitation and adsorption are allowed, these constituents all adjust to values that do not exceed AWQC.

The second approach was developed by Hatch (2015) as a design basis for the conceptual AWT system. It consisted of using 50th percentile and 95th percentile values of source terms. The resulting concentrations are given in the last two columns of Table H-6. The major difference between the two approaches is that the PHREEQC approach predicted that the water would likely eventually turn acidic as the PAG rock oxidized, and the acid would trigger higher concentrations of sulfate, TDS, aluminum, and certain metals. Both approaches predicted that sulfate, TDS, antimony, arsenic, cadmium, lead (when not adsorbed), manganese, molybdenum, nickel, selenium, zinc, and mercury concentrations would exceed AWQC.

### 3.5 Upper CWD

The Upper CWD would receive water from the Lower CWD and runoff from undisturbed areas above the WRF. The relative volumes of the two types of water are predicted to be about 65 percent Lower CWD water and 35 percent runoff from undisturbed areas (BGC 2015f). Parallel to the Lower CWD, two approaches were used to predict the range of water chemistries for the Upper CWD. The first approach used PHREEQC modeling and the second was developed by Hatch (2015) using 50th and 95th percentile data. Because the largest differences between the two approaches for the Lower CWD were between the 50th and 95th percentile data and the PHREEQC model using poorly mixed Peak PAG from Year 26, only this case was modeled. The results for both approaches are given in Table H-7. Sulfate, TDS, antimony, arsenic, cadmium, lead, manganese, molybdenum, nickel, selenium, and mercury are predicted to exceed AWQC for both approaches. Aluminum, cobalt, copper, and iron are also predicted to exceed AWQC using the PHREEQC approach; and ammonia using the Hatch approach.

Table H-7: Predicted Upper CWD Pond Concentrations

Parameter	Units	AWQC	PHREEQC Mix <sup>3</sup>	Water Treatment Design Basis <sup>4</sup>	
				50 <sup>th</sup> Percentile	95 <sup>th</sup> Percentile
Major Constituents					
pH	S.U.	6.5-8.5 <sup>1</sup>	2.9	7.9	8.1
Calcium	mg/L		76	110	120
Potassium	mg/L		12	13	17
Magnesium	mg/L		210	14	18
Sodium	mg/L		18	12	22
Strontium	mg/L			1.6	2.1
Chloride	mg/L	230 <sup>2b</sup>	1.4	1.0	1.3
Fluoride	mg/L	1 <sup>2e</sup>		0.15	0.16
Sulfate	mg/L	250 <sup>1</sup>	1,500	280	330
Silica	mg/L			16	16.9
Total Dissolved Solids	mg/L	500 <sup>1</sup>	1,900	519	614
Ammonia	as N mg/L	0.18 <sup>2g</sup>		0.54	0.55
Cyanide					
WAD Cyanide	µg/L	5.2 <sup>2b</sup>		5	5
Metals					
Aluminum	µg/L	87/750 <sup>2a,b</sup>	32,000	73	121
Antimony	µg/L	6 <sup>2d</sup>	330	420	480
Arsenic	µg/L	10 <sup>2d</sup>	270	2,400	2,900
Barium	µg/L	2,000 <sup>2d</sup>	39	120	180
Beryllium	µg/L	4 <sup>2d</sup>	7.8	48	53
Boron	µg/L	750 <sup>2e</sup>	480	110	110
Cadmium	µg/L	0.64 <sup>2a, b</sup>	4.3	0.8	0.8
Chromium, total	µg/L	100 <sup>2d</sup>	20	13	14
Cobalt	µg/L	50 <sup>2e</sup>	86	32	32
Copper	µg/L	29 <sup>2a, b</sup>	220	5	5
Iron	µg/L	1,000 <sup>2b</sup>	87,000	300	470
Lead	µg/L	11 <sup>2a, b</sup>	40	420	480
Lithium	µg/L	2,500 <sup>2e</sup>		62	72
Manganese	µg/L	50 <sup>2f</sup>	2,000	950	1,300
Molybdenum	µg/L	10 <sup>2e</sup>	91	100	120
Nickel	µg/L	100 <sup>2a, b</sup>	210	187	190

Table H-7: Predicted Upper CWD Pond Concentrations

Parameter	Units	AWQC	PHREEQC Mix <sup>3</sup>	Water Treatment Design Basis <sup>4</sup>	
				50 <sup>th</sup> Percentile	95 <sup>th</sup> Percentile
Selenium	µg/L	4.6 <sup>2b</sup>	66	120	140
Thallium	µg/L	1.7 <sup>2f</sup>	0.65	1	1
Vanadium	µg/L	100 <sup>2e</sup>		13	18
Zinc	µg/L	379 <sup>2a,c</sup>	3,300	270	280
Mercury	ng/L	12 <sup>2a</sup>	66	99	110

Notes:

- 1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.
- 2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
- 2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L; otherwise, 87 µg/L.
- 2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.
- 2c Aquatic life for fresh water (acute) criteria.
- 2d Drinking water primary maximum contaminant levels.
- 2e Irrigation water criteria.
- 2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
- 2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.
- 3 PHREEQC chemistry calculations used 65% Lower CWD water, assuming Peak PAG, poorly mixed, Year 26, with precipitation of Ferrihydrite + Adsorption (Table H-6) mixed with 35% undisturbed runoff, approximated by the average surface water concentrations for Category 2 Locations-- background streams in mineralized area (EIS Table 3.7-3).
- 4 Hatch 2015, Table 3-3, rounded to two significant figures.

### 3.6 Tailings Storage Facility

Tailings pond water is formed by recirculation as process water. It is assumed to have a concentration factor of three from initial tailings liquor (Table H-3 and Table H-4), due to the recirculation (SRK 2015a). SRK (2015a) predicted the recirculated TSF pond water using Geochemist's Workbench, a thermodynamic equilibrium code, and allowed precipitation of certain minerals if they had reached saturation in the concentrated water. The results are shown in Table H-8. The "Solubility Constrained" column is checked for those constituents whose concentrations were lowered due to mineral precipitation.

Along with the tailings pond water, two other types of water are likely to exist in the TSF during mine operations. One is pore water in contact with buried tailings. The other is surficial runoff of snowmelt and rainfall from the beach area.

The pore water in contact with buried tailings is expected to equilibrate with the prevailing conditions of the tailings. In the surficial layers, the tailings were assumed to be in equilibrium with atmospheric (non-reducing) conditions. In this case, the pore water may remain similar to the overlying tailings pond water.

Deeper in the tailings, it was assumed that reducing conditions develop that result in reduction of ferric iron to ferrous, and release of tailings components such as arsenic associated with iron. Thermodynamic equilibrium calculations were conducted using dissolved organic carbon (DOC) in the form of residual cyanide and flotation reagents in the process water ("Process

DOC" in Table H-8). The model results suggest that reduction by DOC decreases pH and increases iron and antimony by several orders of magnitude, as well as arsenic by almost a factor of five (Table H-8).

Several constituents are predicted to exceed AWQC for both near-surface and deeper tailings pore water, including pH (low), fluoride, sulfate, TDS (not shown), antimony, arsenic, cadmium, manganese, molybdenum, selenium, and mercury. Iron is predicted to exceed AWQC for the deeper tailings pore water.

Table H-8: Tailings Pond Water and Pore-Water Quality in Buried Tailings

Parameter	Units	AWQC	Solubility Constrained	Tailings Pond Water	Buried Tailings – Process DOC
Major Constituents					
Redox Potential	mV			840	230
pH	S. U.	6.5-8.5 <sup>1</sup>	X	6.5	5.8
Calcium	mg/L		X	610	1,000
Magnesium	mg/L		X	440	1,000
Potassium	mg/L		X	120	120
Sodium	mg/L			1,100	1,100
Strontium	mg/L			7.9	7.9
Chloride	mg/L	230 <sup>2b</sup>		26	25
Fluoride	mg/L	1 <sup>2e</sup>	X	2	2
Sulfate	mg/L	250 <sup>1</sup>	X	5,800	4,400
Silicon	mg/L			7	7
Alkalinity	mg/L	20 (min) <sup>2b</sup>		25	530
Ammonia	mg/L	0.18 <sup>2g</sup>		29	29
Metals					
Aluminum	µg/L	87 <sup>2a</sup>	X	13	5.6
Antimony	µg/L	6 <sup>2d</sup>	X	22	1,100
Arsenic	µg/L	10 <sup>2d</sup>	X	3,300	15,000
Barium	µg/L	2,000 <sup>2d</sup>	X	11	11
Beryllium	µg/L	4 <sup>2d</sup>		<0.06	<0.06
Boron	µg/L	750 <sup>2e</sup>		590	590
Cadmium	µg/L	0.64 <sup>2a,b</sup>		0.73	0.73
Chromium	µg/L	100 <sup>2d</sup>		12	12
Cobalt	µg/L	50 <sup>2e</sup>		19	19
Copper	µg/L	29 <sup>2a,b</sup>	X	18	18
Iron	µg/L	1,000 <sup>2b</sup>	X	4.4	98,000

Table H-8: Tailings Pond Water and Pore-Water Quality in Buried Tailings

Parameter	Units	AWQC	Solubility Constrained	Tailings Pond Water	Buried Tailings – Process DOC
Lead	µg/L	11 <sup>2a,b</sup>		3	3
Lithium	µg/L	2,500 <sup>2e</sup>		<6	<6
Manganese	µg/L	50 <sup>2f</sup>	X	2,000	2,000
Molybdenum	µg/L	10 <sup>2e</sup>		230	230
Nickel	µg/L	100 <sup>2a,b</sup>		62	62
Selenium	µg/L	4.6 <sup>2b</sup>		42	42
Thallium	µg/L	1.7 <sup>2f</sup>		0.41	0.41
Vanadium	µg/L	1,000 <sup>e</sup>		4.8	4.8
Zinc	µg/L	379 <sup>2a,c</sup>		33	33
Mercury	ng/L	12 <sup>2a</sup>		10,000 <sup>3</sup>	10,000 <sup>3</sup>

Notes:

All tailings pond water and pore-water concentrations are “dissolved” and should be used as “average” annual. Shaded cells exceed most stringent water quality standard.

AWQC:

- 1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.
- 2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
  - 2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L.
  - 2b Aquatic life for fresh water (chronic) criteria.
  - 2c Aquatic life for fresh water (acute) criteria.
  - 2d Drinking water primary maximum contaminant levels.
  - 2e Irrigation water criteria.
  - 2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
  - 2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.
- 3 Hatch 2015; Donlin 2015, personal communication (RE: Hg in TSF pond water email from Gene Weglinski to Nancy Darigo, Aug 26, 2015).

Source: SRK 2015a.

The beach runoff water was estimated assuming that the humidity cell discussed in EIS Section 3.7.2.4.4, Water Quality, could be used as an analog for beach runoff, in combination with average annual net precipitation data for the site (SRK 2007). The beach runoff is predicted to be relatively dilute due to exposure of the water to only a thin layer of tailings, as shown in Table H-9. However, several constituents are predicted to exceed AWQC, including sulfate, antimony, arsenic, manganese, molybdenum, selenium, and mercury. Alkalinity is expected to be lower than required by AWQC.

Table H-9: Beach Runoff Water Quality at Tailings Storage Facility

Parameter	Units	AWQC	Concentration
Major Constituents			
Sulfate	mg/L	250 <sup>1</sup>	520
Alkalinity	mg/L	20 (min) <sup>2b</sup>	11
Calcium	mg/L	-	140
Sodium	mg/L	--	4.2
Magnesium	mg/L	-	32
Metals			
Aluminum	µg/L	750 <sup>2a,b</sup>	290
Antimony	µg/L	6 <sup>2d</sup>	81
Arsenic	µg/L	10 <sup>2d</sup>	290
Barium	µg/L	2,000 <sup>2d</sup>	11
Beryllium	µg/L	4 <sup>2d</sup>	0.15
Cadmium	µg/L	0.64 <sup>2a,b</sup>	0.22
Chromium	µg/L	100 <sup>2e</sup>	1.1
Cobalt	µg/L	50 <sup>2e</sup>	2.7
Copper	µg/L	29 <sup>2a,b</sup>	2.7
Iron	µg/L	1,000 <sup>2b</sup>	39
Lead	µg/L	11 <sup>2,ba</sup>	0.1
Manganese	µg/L	50 <sup>2f</sup>	1,100
Molybdenum	µg/L	10 <sup>2e</sup>	38
Nickel	µg/L	100 <sup>2d</sup>	9.2
Selenium	µg/L	4.6 <sup>2b</sup>	11
Silver	µg/L	34.9 <sup>2a,c</sup>	0.11
Thallium	µg/L	1.7 <sup>2f</sup>	0.37
Zinc	µg/L	379 <sup>2a,c</sup>	11
Mercury	ng/L	12 <sup>2b</sup>	51

Notes:

All beach runoff concentrations are "dissolved" and should be used as "average" annual. Shaded cells exceed most stringent water quality standard.

- 1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.
- 2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column.
  - 2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L; otherwise 87 µg/L.
  - 2b Aquatic life for fresh water (chronic) criteria.
  - 2c Aquatic life for fresh water (acute) criteria.
  - 2d Drinking water primary maximum contaminant levels.
  - 2e Irrigation water criteria.
  - 2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

Source: SRK 2012b, Table 5-5.

### 3.7 TSF Seepage Recovery System

A Seepage Recovery System (SRS) would be built at the downstream toe of the TSF that consists of a collection pond, groundwater monitoring and collection wells, and pumping system. It is designed to capture two sources of water: 1) potential seepage through the TSF liner and 2) surface water and groundwater that enters the rock underdrains (BGC 2011a). The SRS water may be treated at the WTP and discharged to Crooked Creek, when needed, for water management.

Due to the TSF liner, the seepage is expected to be minimal, ranging from about 1.4 gpm in Year 1 to about 17.6 gpm in Year 27 (BGC 2015f). Flows from surface water and groundwater are expected to vary seasonally, with higher flow rates in summer than in winter. Flows are expected to increase over the first few years, and then taper off again slowly by the end of mine life. Summer flows are predicted to range between about 570 gpm (at end of mine life) to about 1,030 gpm (around Year 5); whereas winter flows are predicted to range between about 90 to 710 gpm.

SRS water chemistry (Table H-10) is predicted to be neutral pH. Sulfate, ammonia, TDS, WAD cyanide, antimony, arsenic, iron, manganese, molybdenum, selenium, and mercury concentrations are expected to exceed AWQC (Hatch 2015).

Table H-10: Predicted TSF Seepage Recovery System Water Quality

Parameter	Units	AWQC	Seepage Recovery System	
			50 <sup>th</sup> Percentile	95 <sup>th</sup> Percentile
Major Constituents				
pH		6.5-8.5 <sup>1</sup>	7.2	7.8
Calcium	mg/L		122	128
Magnesium	mg/L		110	112
Potassium	mg/L		13.2	15.4
Sodium	mg/L		121	122
Chloride	mg/L	230 <sup>2b</sup>	3.2	3.6
Fluoride	mg/L	1 <sup>2e</sup>	0.303	0.303
Sulfate	mg/L	250 <sup>1</sup>	471	474
Ammonia	as N mg/L	0.18 <sup>2g</sup>	3.1	3.2
Total Dissolved Solids	mg/L	500 <sup>1</sup>	905	919
Cyanide				
WAD Cyanide	µg/L	5.2 <sup>2b</sup>	30	32
Metals				
Aluminum	µg/L	750 <sup>2a,b</sup>	19	43
Antimony	µg/L	6 <sup>2d</sup>	120	120
Arsenic	µg/L	10 <sup>2d</sup>	1,610	1,610

Table H-10: Predicted TSF Seepage Recovery System Water Quality

Parameter	Units	AWQC	Seepage Recovery System	
			50 <sup>th</sup> Percentile	95 <sup>th</sup> Percentile
Barium	µg/L	2,000 <sup>2d</sup>	60	90
Beryllium	µg/L	4 <sup>2d</sup>	0.4	2
Boron	µg/L	750 <sup>2e</sup>	85	110
Cadmium	µg/L	0.64 <sup>2a,b</sup>	0.3	0.52
Chromium, total	µg/L	100 <sup>2e</sup>	2	3
Cobalt	µg/L	50 <sup>2e</sup>	2.2	3.1
Copper	µg/L	29 <sup>2a,b</sup>	2.4	2.8
Iron	µg/L	1,000 <sup>2b</sup>	10,600	10,700
Lead	µg/L	11 <sup>2a,b</sup>	0.4	0.5
Lithium	µg/L	2,500 <sup>2e</sup>	5	5
Manganese	µg/L	50 <sup>2f</sup>	230	270
Molybdenum	µg/L	10 <sup>2e</sup>	29	34
Nickel	µg/L	100 <sup>2a</sup>	7.5	8.4
Selenium	µg/L	4.6 <sup>2b</sup>	6.7	6.7
Thallium	µg/L	1.7 <sup>2f</sup>	0.5	0.1
Vanadium	µg/L	100 <sup>2e</sup>	5	20
Zinc	µg/L	379 <sup>2a,c</sup>	6	8
Mercury	ng/L	12 <sup>2b,3</sup>	1,070	1,080

Notes:

Values exceeding discharge criteria are highlighted.

- 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels
- Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
  - Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L; otherwise, 87 µg/L.
  - Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.
  - Aquatic life for fresh water (acute) criteria.
  - Drinking water primary maximum contaminant levels.
  - Irrigation water criteria.
  - Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
  - Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.
- Mercury concentrations are after Year 18 during late winter with minimal SRS underdrain flow. The maximum WTP feed concentration considered for design is 137 ng/L. Reference: Rieser, 2015c.

Source: Hatch 2015.

### 3.8 Open Pit

During operations, water collected from pit dewatering would report to the Lower CWD for storage. When the combined pond volume of the Lower and Upper CWD exceeds 1,216 acre-



feet, this water would be treated, as needed, and discharged to Crooked Creek (BGC 2015f). The predicted chemistry of the pit dewatering wells is given in EIS Table 3.7-38, Water Quality.

## 4. Closure

According to the mine plan, in Year 22 of the mine life, the final limits of the pit would be reached. At this point, all PAG 6 and PAG 7 waste rock mined in the Lewis Pit would be placed as backfill into the ACMA Pit. At least some rock classified as NAG 1-4 and PAG 5 rock would also be backfilled into the ACMA Pit as it is mined from the Lewis Pit (SRK 2012e). Closure of the overburden stockpiles, WRF, low grade ore stockpile, and the TSF and formation of the closure pit lake that includes collection of drainage from the closed WRF and TSF are discussed in the following sections.

### 4.1 Waste Rock Facility

The WRF is planned to be progressively reclaimed during operations by placing a cover designed to reduce infiltration and provide natural drainage toward the south margin of the WRF (SRK 2012e). At mine closure, seepage from the both NAG and PAG portions of the WRF is expected to continue to exceed AWQC for several constituents (Table H-11). Sulfate, antimony, arsenic, cadmium, lead, manganese, nickel, selenium, zinc, and mercury concentrations are predicted to exceed AWQC for both NAG and PAG seepage. Additionally, aluminum, copper, and chromium concentrations exceed AWQC for PAG seepage.

The seepage from the WRF would flow to a collection area, and be gravity-piped to a deep layer of the pit lake. Over time, it is expected that the quality of seepage from the PAG 6 cells will improve. However, piping of the combined WRF seepage to the pit lake may need to continue indefinitely because PAG 5 rock in the WRF is predicted to have the potential to generate ARD only after several decades (SRK 2007).

Table H-11: Water Quality of Major Inflows to Pit at Closure

Parameter	Units	AWQC	NAG WRF Seepage <sup>3</sup>	PAG Cell Seepage <sup>4</sup>	Initial Pit Lake Water <sup>5</sup>	Tailings Pore-water Seepage <sup>6</sup>	Groundwater <sup>7</sup>	Undisturbed Reclamation Runoff <sup>8</sup>
pH	Units	6.5-8.5 <sup>1</sup>	7.7	3.5	7.7	7.7	7.3	6.4
Sulfate	mg/L	250 <sup>1</sup>	2,000	180,000	3,811	4,400	9	20
Aluminum	µg/L	87/750 <sup>2a,b</sup>	29	30,000,000	221	5.6	81	1,100
Antimony	µg/L	6 <sup>2d</sup>	3,100	2,800	1,630	1,100	0.5	3
Arsenic	µg/L	10 <sup>2d</sup>	21,000	27,000	12,600	15,000	100	12
Boron	µg/L	750 <sup>2e</sup>	200	200	390	590	30	20
Cadmium	µg/L	0.64 <sup>2a,b</sup>	1.3	65	1	7.3	0.25	0.25
Copper	µg/L	29 <sup>2a,b</sup>	25	33,000	22	18	1.5	1
Chromium	µg/L	100 <sup>2e</sup>	31	130	22	12	1	2
Lead	µg/L	50 <sup>2a,b</sup>	1,300	460	680	3	0.1	1.2
Manganese	µg/L	50 <sup>2f</sup>	8,800	170,000	5,600	2,000	220	260
Nickel	µg/L	100 <sup>2d</sup>	1,600	2,300	870	62	1	2.9

Table H-11: Water Quality of Major Inflows to Pit at Closure

Parameter	Units	AWQC	NAG WRF Seepage <sup>3</sup>	PAG Cell Seepage <sup>4</sup>	Initial Pit Lake Water <sup>5</sup>	Tailings Pore-water Seepage <sup>6</sup>	Groundwater <sup>7</sup>	Undisturbed Reclamation Runoff <sup>8</sup>
Selenium	µg/L	4.6 <sup>2b</sup>	860	80,000	470	42	2.5	2.5
Zinc	µg/L	379 <sup>2a,c</sup>	7,600	190,000	4,000	33	3	9
Cyanide, WAD	µg/L	5.2 <sup>2b</sup>	0	0	60	100	0	0
Mercury	ng/L	12 <sup>2b</sup>	190	180	34,900	73,000	2.2	14

Notes:

Shaded cells exceed most stringent water quality standard.

AWQC

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L, otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.

3 75th Percentile chemistry for well mixed NAG at year 2036 based on scaling of humidity cell leachate data (SRK 2015c).

4 75th Percentile chemistry for poorly mixed PAG at year 2050 2036 based on scaling of humidity cell leachate data (SRK 2012h2015c).

5 Conservative mixture of 8,920 acre-feet of backfill runoff and 24,000 acre-feet of tailings supernatant water.

6 Predicted concentrations of tailings pore water (SRK 2015a).

7 Denotes mean background groundwater quality in the mineralized area of the pit shell. Data collected from site monitoring wells MW03-1, MW03-2, MW03-4, MW03-14, MW03-15, MW03-16, and MW05-23 during the period from March 2004 until December 2010.

8 95th Percentile chemistry for background surface water quality in American Creek (2004 to 2010).

Source: Lorax 2015, Table 2-1.

## 4.2 Low-Grade Ore Stockpile

At or before closure, all materials remaining in the low-grade ore stockpile would be transferred as backfill into the ACMA Pit (SRK 2012c).

## 4.3 Tailings Storage Facility

In preparation for closure, the operating pond would gradually be shifted to the southeast corner of the TSF by modifying the direction of tailings deposition. At closure, the tailings water is expected to continue to exceed water-quality standards (EIS Table 3.7-30, Water Quality) and the pond water would be pumped to a deep layer of the pit lake. The TSF would be covered with a coarse NAG waste rock drain layer overlain by colluvium/terrace gravel, in turn overlain by a growth media mix with a slope to promote controlled surface runoff and reduce infiltration into the tailings. It is predicted that over the 5-year closure period, the cover would induce consolidation of the underlying tailings.

The expelled tailings water, along with infiltration through the overlying cover, would flow through the coarse rock layer to the (then) small lined impoundment located on the southeast corner of the TSF. The water would continue to be pumped from the small impoundment to the

pit rim, where it would be combined with WRF drainage. From there, it would be gravity-piped to the pit lake bottom until AWQC are met. Thereafter, flow from the TSF would be discharged to Crevice Creek (SRK 2012f). The consolidation water is predicted to decrease exponentially from approximately 1,000 acre-feet/year to 400 acre-feet/year during the first 10 years after closure, and to approximately 100 acre-feet/year by Year 51 (BGC 2014b). It is expected that the water quality would improve rapidly with time as consolidation reaches completion and the rate of consolidation decreases, such that, by approximately Year 52 post-closure, the flow would be essentially all infiltrated precipitation. At that time it is predicted that water quality standards would be met, and that the consolidation water would no longer be routed to the pit lake (final volume approximately 380,000 acre-feet [BGC 2012c]), but rather discharged directly to Crevice Creek. (For flow-rate comparisons, the annual average Crooked Creek flow at Crevice Creek is on the order of 70,000 acre-feet/year [BGC 2014i].)

## 4.4 Pit Lake

### 4.4.1 Lake Depth, Inflow Sources, and Gradient

Starting in Year-22 of the mine life, all Lewis Pit PAG 6 and PAG 7 waste rock, as well as some NAG 1-4 and PAG 5 rock would be placed as backfill into the ACMA Pit (SRK 2012e). The backfill would be such that the maximum depth of the deepest part of the post-closure pit lake would be approximately 1,020 to 1,050 feet. Other portions of the pit would be backfilled to maintain a shallower lake depth of approximately 205 to 216 feet (SRK 2012b, e).

After closure, pit dewatering would stop and the pit would fill with water from several sources (Lorax 2012a), including:

- Groundwater inflows;
- Highwall precipitation runoff;
- Direct precipitation on the surface of the pit lake;
- Excess tailings water in the impoundment at the end of operations;
- Tailings consolidation water and cover infiltration water;
- Tailings seepage recovery system (SRS) water consisting of natural groundwater and a small component of tailings pore water;
- NAG seepage water from the WRF;
- PAG seepage water from the isolated cells of the WRF; and
- Undisturbed runoff from American Creek watershed and runoff from the WRF reclamation cover.

According to the numerical hydrogeologic model developed by BGC (2011d, 2015g), for about 8 years after pit dewatering is stopped, water would flow into the pit from the groundwater at higher elevations and from the pit into the pore space of the waste rock placed as backfill and into the localized bedrock outside of and surrounding the pit from which bedrock water had been removed during mining. Once the localized bedrock had refilled with water, the direction of flow would reverse and groundwater would move towards the pit (pit lake). Thereafter, the seepage rate from the lake to groundwater would gradually decrease to zero as the lake reaches its managed final elevation approximately 10 to 30 feet below the designed spillway overflow

elevation of 349 feet AMSL (BGC 2015g). Additional description of the temporary localized flow reversal into bedrock as the pit fills is given in EIS Section 3.6, Groundwater Hydrology. The pit outflow may result in an elevated input of sulfate and metals and decreased pH to the deep bedrock portion of the aquifer for the first few years. Pit lake levels would be managed in post-closure to maintain a net inward groundwater gradient to the pit by pumping from the lake surface and treating it at the WTP for discharge to Crooked Creek (SRK 2012b, f; BGC 2014b).

Treatment and discharge of pit lake surface water are predicted to begin approximately 53 years after closure, based on the most likely pit filling rate obtained in the BGC (2015g) hydrogeological model. Hydrogeologic sensitivity runs suggested that the timing of pit lake filling could be as little as 30 years, assuming a future wet climate due to climate change or a higher hydraulic conductivity, or as long as 60 years. The uncertainty in the pit filling rate is discussed in more detail in EIS Section 3.6, Groundwater Hydrology.

Most WRF seepage would report to the WRF underdrain, and from there, would flow by gravity to the pit rim. Pumping would be required to get TSF and SRS water to the pit rim, where it would be combined with the WRF seepage, then flow via a gravity-fed pipe to the bottom of the pit lake. Groundwater seepage through the pit walls could possibly contain a small fraction of WRF seepage that leaks below the WRF underdrain, but this is expected to be a very minor contribution to the pit lake in comparison to the piped flows and overall groundwater seepage from around the pit. The denser TSF/WRF water piped to the bottom of the pit lake would likely stay below the pycnocline. Groundwater seepage into the pit lake through the walls would likely be less dense than the TSF/WRF water. EIS Section 3.6, Groundwater Hydrology further describes the inflows and water balance in relation to the pit lake.

#### 4.4.2 Pit Lake Modeling

Lorax (2012a) modeled the evolution of the post-closure pit lake to assess the physics and geochemistry of the pit filling process, confirm the assumption that the pit lake would stratify, and predict the quality of the water that would eventually be discharged from the lake (SRK 2012b). The model was run for 100 model years, starting at Year 0 at closure. The initial modeling and sensitivity runs were done under assumptions of an operations water management plan that allowed no discharge of process or seepage waters. When the AWT option was introduced as part of Alternative 2, a revised model was developed (Lorax 2015).

##### 4.4.2.1 Methods and Assumptions

A one-dimensional (vertical) model, PitMod, was developed by Lorax to model pit lake chemistry development. The model assumes uniformity in both horizontal dimensions and the water column divided into a vertical stack of 3.3 feet (1 meter) thick homogeneous layers. The assumption of horizontal homogeneity is based on the high depth to surface area ratio and the absence of horizontal mixing, as well as knowledge of other pit lakes, in which major chemical and physical variations are in the vertical. It has been validated for the Island Copper Mine in British Columbia (BC), Canada, and in a three-year Canadian government-funded study of water properties in the two Equity Mine pit lakes in north Central BC (Lorax 2012a).

The physical and hydrodynamic processes simulated by the model include: solar heating of the lake surface; ice formation and decay; surface and groundwater inflows and outflows; wind mixing; and vertical mixing as a function of the density structure of the water column due to

heating and cooling of the lake water and differences in the TDS and chemical-constituent content of the water at different depths.

Model physical inputs include pit morphometry, the site water balance, and high-temporal-resolution meteorological data. The meteorological data, including wind speed and direction, precipitation, evaporation, relative humidity, incoming and out-going radiation, and percent cloud cover, were used to create a 200-year synthetic meteorological database. Model geochemical/water-quality inputs include the Donlin Gold baseline water-quality database, SRK's assessment of various impacted water sources, and mapping of exposed pit-wall geology.

PitMod has the ability to couple the hydrodynamic model with a customized version of PHREEQC (Parkhurst and Appelo 1999). PHREEQC allows geochemical equilibrium calculations such as element speciation and mineral precipitation and dissolution. However, the PHREEQC component was not used for the initial intensive modeling effort. Instead, constituent concentrations were calculated based on conservative mixing with no reactions, which thus yielded higher surface-water concentrations (Lorax 2012a). Later modeling included a run allowing common low-temperature minerals, such as ferric hydroxide, to precipitate if supersaturated. The pit lake is assumed to be oligotrophic with no interaction between bottom waters and backfill (Lorax 2012a).

#### 4.4.2.2 Model Input Chemistries

The predicted water quality of the various major inflows into the pit lake varies several orders of magnitude from direct precipitation and snowmelt with essentially no TDS, to low-TDS runoff from reclaimed areas and groundwater, to highly saline PAG seepage from the isolated cells of the WRF. Table H-11 shows the predicted (75<sup>th</sup> percentile) annual average concentrations from major inflows, assuming AWT during operations. Table H-12 shows a comparison of the chemistries used under the AWT assumption and the assumption of the initial no-discharge water management plan (labeled "base case") for sources whose predicted chemistries changed under the different assumptions.

Table H-12: Water Quality of Major Inflows to Pit at Closure, Comparison of AWT and Base Case Inputs

Parameter	Units	AWQC	PAG Cell Seepage		Initial Pit Lake Water		Tailings Pore-water Seepage	
			AWT3	Base Case <sup>4</sup>	AWT <sup>5</sup>	Base Case <sup>6</sup>	AWT <sup>7</sup>	Base Case <sup>8</sup>
pH	Units	6.5-8.5 <sup>1</sup>	3.5	4.1	7.7	7.7	7.7	5.5
Sulfate	mg/L	250 <sup>1</sup>	180,000	42,450	3,811	10,537	4,400	15,900
Total Dissolved Solids (est.)	mg/L	500 <sup>1</sup>	210,000	160,000	5,500	14,000	8,300	23,000
Aluminum	µg/L	87/750 <sup>2a,b</sup>	30,000,000	30,4700,000	221	18.14	5.6	1.9
Antimony	µg/L	6 <sup>2d</sup>	2,800	2,800	1,630	920	1,100	1,160
Arsenic	µg/L	10 <sup>2d</sup>	27,000	27,000	12,600	6,600	15,000	15,700
Cadmium	µg/L	0.64 <sup>2a,b</sup>	65	65	1	0.7	7.3	0.93

Table H-12: Water Quality of Major Inflows to Pit at Closure, Comparison of AWT and Base Case Inputs

Parameter	Units	AWQC	PAG Cell Seepage		Initial Pit Lake Water		Tailings Pore-water Seepage	
Copper	µg/L	29 <sup>2a,b</sup>	33,000	35,600	22	310	18	674
Chromium		100 <sup>2e</sup>	130	130	22	11	12	7.23
Lead	µg/L	11 <sup>2a,b</sup>	460	99	680	350	3	82.5
Manganese	µg/L	50 <sup>2f</sup>	170,000	370,300	5,600	43,200	2,000	45,600
Selenium	µg/L	4.6 <sup>2b</sup>	80,000	18,790	470	330	42	220
Zinc	µg/L	379 <sup>2a,c</sup>	190,000	3,991,000	4,000	2,100	33	79
Mercury	ng/L	12 <sup>2b</sup>	180	150	34,900	720	73,000	1,440

Notes:

Shaded cells exceed most stringent water quality standard.

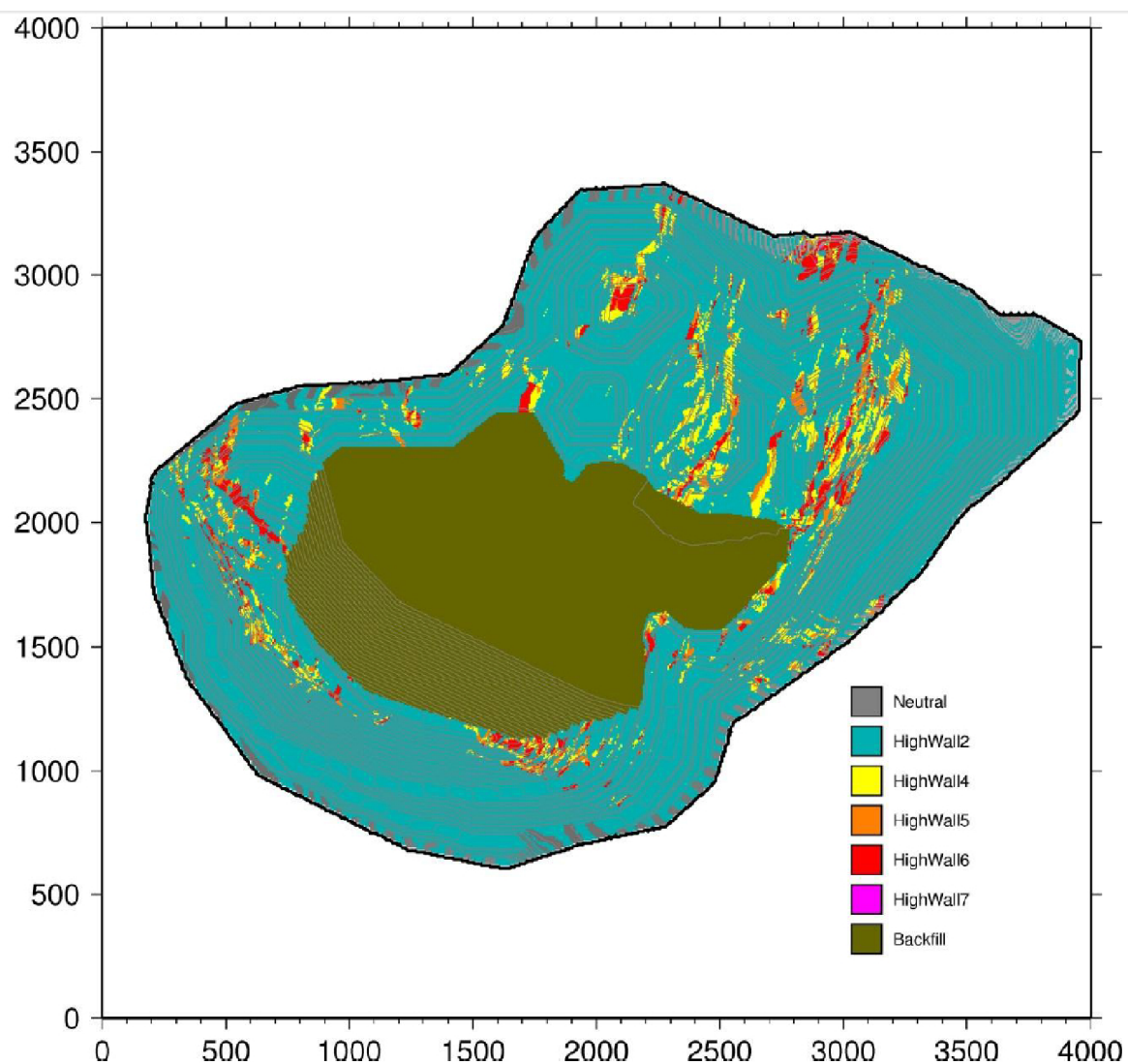
AWQC

- 1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.
- 2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
  - 2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L, otherwise, 87 µg/L.
  - 2b Aquatic life for fresh water (chronic) criteria.
  - 2c Aquatic life for fresh water (acute) criteria.
  - 2d Drinking water primary maximum contaminant levels.
  - 2e Irrigation water criteria.
  - 2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
- 3 75th Percentile chemistry for poorly mixed PAG at year 2050 based on scaling of humidity cell leachate data (SRK 2015c).
- 4 75th Percentile chemistry for poorly mixed PAG at year 2050 based on scaling of humidity cell leachate data (SRK 2012h).
- 5 Conservative mixture of 8,920 acre-feet of backfill runoff and 24,000 acre-feet of tailings supernatant water (Lorax 2015).
- 6 Conservative mixture of 8,920 acre-feet of backfill runoff and 24,000 acre-feet of tailings supernatant water (Lorax 2012a).
- 7 Predicted concentrations of tailings pore water (SRK 2015a).
- 8 Predicted concentrations of tailings pore water (Lorax 2012a).

#### 4.4.2.3 Effect of Pit Highwall Runoff

Table H-11 and Table H-12 do not include the predicted chemistries of pit highwall runoff for the various categories of rock. As shown in Table H-3, at least six categories of rock in terms of acid generating potential are expected to be exposed on the pit highwalls at closure. Two sets of predictions were developed by SRK (2007) of the water quality to be expected from each of the NAG and PAG categories (Table H-13): the first, labeled Peak, was the water quality expected from pit wall runoff during peak oxidation of the PAG rocks; and the second, labeled Exhausted, was the water quality expected once the PAG rocks had essentially exhausted their sulfide content and would produce only dilute water chemistry, which is of higher quality than NAG rock runoff for most constituents. As shown in Table H-14, the actual water quality used for the initial base case pit lake modeling predictions and sensitivity runs for PAG rocks is more similar to the Exhausted PAG chemistry than the Peak PAG chemistry and contains lower concentrations than the water quality used for the AWT model. Highwall rock with the PAG rock chemistry used for the base case and the sensitivity runs is hereafter referred to as exhausted PAG rock.





Data Sources: Lorax 2012



DONLIN GOLD  
PROJECT EIS



## HIGHWALL GEOLOGY ON EXPOSED PIT WALLS AT CLOSURE

NOVEMBER 2015

APPENDIX H FIGURE 3

Table H-13: Water Quality of Pit Wall Runoff

Parameter	Units	AWQS	WRMC						Peak Acid Walls			Exhausted Acid Walls		
			1	2	3	4	5	6	Peak 5	Peak 6	Peak 7	5	6	7
Major Constituents														
pH	pH Units	6.5-8.5 <sup>1</sup>	8.3	8.1	7.8	7.8	7.7	7.8	2.9	2.5	2.4	4.0	4.4	4.6
Calcium	mg/L	-	29	32	210	210	340	290	35	170	230	0.26	0.77	0.98
Magnesium	mg/L	-	2.9	17	66	66	140	46	47	230	310	0.35	1	1.3
Potassium	mg/L	-	35	25	23	23	9.7	47	2.5	13	17	0.019	0.057	0.074
Sodium	mg/L	-	7.3	1.7	3.5	3.5	1.1	66	47	240	320	0.35	1.1	1.4
Sulfate	mg/L	250 <sup>1</sup>	81	140	770	770	1,300	1,000	1,500	7,200	9,600	11	32	41
Acidity	mg/L as CaCO <sub>3</sub>		0.029	0.023	0.018	0.018	0.018	0.019	12	7,500	10,000	11	33	43
Alkalinity	mg/L as CaCO <sub>3</sub>	20 (min) <sup>2b</sup>	61	41	25	25	21	27	0	0	0	1	1	1
Metals														
Aluminum	µg/L	87/750 <sup>2a,b</sup>	1.6	1.1	0.66	0.66	0.55	0.7	50,000	250,000	330,000	370	1,100	1,400
Antimony	µg/L	6 <sup>2d</sup>	700	360	250	250	130	240	250	280	280	1.9	1.2	1.2
Arsenic	µg/L	10 <sup>2d</sup>	270	560	900	900	6,100	17,000	26,000	77,000	77,000	190	340	330
Barium	µg/L	2,000 <sup>2d</sup>	6.4	1.7	5.7	5.7	5.1	5.3	5.2	4.2	4.1	0.039	0.019	0.018
Beryllium	µg/L	4 <sup>2d</sup>	0.4	0.4	0.4	0.4	0.4	0.4	54	270	360	0.4	1.2	1.5
Cadmium	µg/L	0.64 <sup>2a,b</sup>	0.5	0.5	0.5	0.5	0.5	0.5	16	77	100	0.12	0.34	0.44
Chromium	µg/L	100 <sup>2d</sup>	31	31	31	31	31	31	71	350	470	0.53	1.6	2
Cobalt	µg/L	50 <sup>2e</sup>	17	17	22	22	18	64	450	2,200	3,000	3.4	9.9	13
Copper	µg/L	29 <sup>2a,b</sup>	3.7	6.5	17	17	16	17	100	5,500	7,300	8.3	24	31



Table H-13: Water Quality of Pit Wall Runoff

Parameter	Units	AWQS	WRMC						Peak Acid Walls			Exhausted Acid Walls		
			1	2	3	4	5	6	Peak 5	Peak 6	Peak 7	5	6	7
Iron	µg/L	1,000 <sup>2b</sup>	1.9	2	2.1	2.1	2.1	2.1	23,000	150,000	210,000	2,400	580	440
Lead	µg/L	11 <sup>2a,b</sup>	17	17	17	17	15	22	35	170	230	0.26	0.77	0.98
Manganese	µg/L	50 <sup>2f</sup>	400	310	1,200	1,200	180	4,800	5,600	27,000	37,000	42	120	160
Molybdenum	µg/L	10 <sup>2e</sup>	160	140	23	23	18	100	9.4	9.4	9.4	0.07	0.04	0.04
Nickel	µg/L	100 <sup>2a,b</sup>	86	83	85	85	79	150	1,500	7,200	7,300	11	32	31
Selenium	µg/L	4.6 <sup>2b</sup>	170	160	170	170	120	170	110	520	700	0.78	2.3	3
Silver	µg/L	34.9 <sup>2a,b</sup>	1	1	1	1	1	1	0.62	0.62	0.62	0.0046	0.0027	0.0026
Thallium	µg/L	1.7 <sup>2f</sup>	1	1	1	1	1	1	1.9	1.9	1.9	0.014	0.0085	0.0081
Zinc	µg/L	379 <sup>2a,c</sup>	97	83	85	85	62	160	6,200	30,000	41,000	46	130	17,000
Mercury	ng/L	12 <sup>2d</sup>	77	77	77	77	77	77	150	150	150	1.1	0.68	0.65

Notes:

All concentrations are “dissolved” and should be used as “average” annual.

Shaded cells exceed most stringent water quality standard.

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 400 mg/L was used for all calculations. For aluminum, if pH≥7.0 and hardness ≥50, then 750 µg/L; otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria. Free cyanide measured as weak acid dissociable (WAD) cyanide.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

2g Aquatic life for fresh water (chronic) criteria based on pH and temperature when early life stages of fish are present.

Source: SRK 2007, Table 3-1.

Table H-14: Water Quality of Runoff from Backfill and Highwall Waste Rock Used in Base Case Pit Lake Model for Constituents Expected to Exceed AWQS (Exhausted-PAG Wall Rock)

Parameter	Units	AWQC	Category Backfill	Category 2	Category 4	Category 5	Category 6	Category 7
pH	Units	6.5-8.5 <sup>1</sup>	7.7	8.0	7.7	4.0	3.7	3.7
Sulfate	mg/L	250 <sup>1</sup>	1,964	150	1,700	11	6	6
Antimony	µg/L	6 <sup>2d</sup>	3,100	600	710	1	0.1	0.1
Arsenic	µg/L	10 <sup>2d</sup>	20,800	510	5,900	5.1	24,000	24,000
Cadmium	µg/L	0.64 <sup>2a,b</sup>	1.25	1.3	1.1	0.1	0.06	0.06
Copper	µg/L	29 <sup>2a,b</sup>	25	4	5	9.7	9.7	9.7
Iron	µg/L	1,000 <sup>2b</sup>	2.1	2	2	2,400	6,600	6,600
Lead	µg/L	11 <sup>2a,b</sup>	1,300	18	1.7	9.7	9.7	9.7
Manganese	µg/L	50 <sup>2f</sup>	8,770	310	390	9.7	9.7	9.7
Selenium	µg/L	4.6 <sup>2b</sup>	864	180	22	0.8	0.4	0.4
Thallium	µg/L	1.7 <sup>2f</sup>	1	1	1	<0.1	<0.1	<0.1
Zinc	µg/L	379 <sup>2a,c</sup>	7,600	92	41	10	10	10
Mercury	ng/L	12 <sup>2b</sup>	180	190	190	1	0.1	0.1

Notes:

Categories 2 through 7 refer to waste rock NAG and PAG classifications in Table 3.7-2 of the EIS.

Shaded cells exceed most stringent water quality standard.

AWQC

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of >400 mg/L was used for all calculations. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L, otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

Source: Lorax 2012a.

#### 4.4.2.4 Sensitivity Analyses

The base case assumed expected climatic conditions and the input water quality shown in Table H-11 through Table H-14. It also assumed that the initial groundwater inflows had the same chemistry as that of the highwalls, but that the groundwater chemistry would change linearly with time and eventually return to background groundwater quality. Table H-15 shows the predicted surface water quality for the sensitivity runs. The groundwater sensitivity scenario was similar to the base case, except that the groundwater quality remained at the chemistry of the highwall runoff throughout the entire modeling period. In general, the predicted concentrations in surface water increased somewhat from that of the base case. The increase varied from essentially no increase for aluminum to an increase of between 75 and 80 percent for antimony, arsenic, boron, and selenium.

Another factor affecting the stability is the salinity of the water pumped to the bottom of the pit lake. This salinity is controlled mainly by the >20,000 mg/L TDS chemistry of the base-case TSF water (Table H-12) and secondarily by the substantially lower-volume, but higher-TDS PAG seepage from the WRF. The decreased salinity scenario assumed that the TSF seepage was similar to the lower-salinity NAG seepage from the WRF, at a TDS content of 3,000 mg/L. (Note: The TSF seepage used for the AWT model, with a TDS at 8,300 mg/L, is between the base case and low-salinity models, but closer to the low-salinity model.) For the decreased salinity case, the TDS decreased somewhat from the base case, although the metals and sulfate concentrations remained essentially unchanged.

The prior scenarios predicted a permanently stratified lake. Comparison of results from Model Year 53 and Year 99 indicated little change in surface-water chemistry over model time once the pit lake filled. In the complete mixing scenario, a catastrophic mixing event was assumed to occur at one point in the lake history that caused complete overturn and mixing of the lake in year 55, a few years after complete pit filling. This scenario provided an upper bound assessment of the concentrations of constituents predicted in the surface waters of the lake. Following the complete mixing event, salinity would begin to decrease in surface water due to precipitation and undisturbed runoff and a shallow pycnocline would form, such that by Year 99 sulfate concentrations are predicted to decrease to less than 400 mg/L (Lorax 2012a).

The complete mixing event would require strong physical forcing to overcome the stability of the density gradient predicted by expected conditions. Wind forcing is one possibility, so an extreme wind event scenario was conducted by specifying a steady 125 mph wind over a two-day interval during the summer of year 55. The resulting surface water concentrations remained essentially unchanged from the base case scenario.

Neither the decreased salinity nor the extreme wind scenario prevented formation of a permanently stratified lake. Thus the results of the sensitivity analyses suggest that the pit lake would develop a density stratification with poor quality, highly saline bottom waters overlain by low TDS (112 to 142 mg/L) surface water under all likely scenarios (Table H-15). In the base case, as well as all the sensitivity cases except complete mixing, antimony, arsenic, cadmium, lead, manganese, mercury, and selenium concentrations exceeded AWQC. The complete mixing sensitivity run forced the lake to mix completely in Year 55. In that year, the TDS was calculated to be 2,350 mg/L throughout the water column. By Year 99, stratification had re-established, and the surface water TDS had decreased to 918 mg/L (Table H-15, Complete Mixing). In the complete mixing case, even in Year 99, all constituents of interest exceed AWQC, showing the

importance to treatment costs of maintaining a permanently stratified pit lake, because this result would likely require reverse osmosis to treat the TDS.

Table H-15: Surface Water Quality Estimates for Pit Lake at Closure Year 99—Sensitivity Analysis (assuming Exhausted PAG Pit-Wall Runoff and No-Discharge Water Management)

Parameter	Units	AWQC	Base Case	Groundwater Sensitivity	Complete Mixing <sup>3</sup>	Extreme Winds Sensitivity <sup>4</sup>	Decreased Salinity Sensitivity
Sulfate	mg/L	250 <sup>1</sup>	31	48	658	31	30
Total Dissolved Solids	mg/L	500 <sup>1</sup>	135	142	918	137	112
Aluminum	µg/L	87 <sup>2a,b</sup>	310	311	12,700	316	311
Antimony	µg/L	6 <sup>2d</sup>	67	120	216	68	67
Arsenic	µg/L	10 <sup>2d</sup>	112	198	1,060	116	112
Boron	µg/L	750 <sup>2f</sup>	202	356	880	205	199
Cadmium	µg/L	0.18 <sup>a,b</sup>	0.24	0.33	0.4	0.24	0.24
Chromium	µg/L	100 <sup>2e</sup>	4	6.7	7.5	4	4
Copper	µg/L	6.2 <sup>2a,b</sup>	1.4	1.7	32	1.4	1.4
Lead	µg/L	1.6 <sup>2a,b</sup>	2.3	3.8	38	2.3	2.2
Manganese	µg/L	50 <sup>2f</sup>	128	136	2,350	131	128
Nickel	µg/L	36 <sup>2a,b</sup>	11	19	70	12	11
Selenium	µg/L	4.6 <sup>2b</sup>	20	36	70	21	20
Zinc	µg/L	81 <sup>2a,c</sup>	13	21	304	14	13
Mercury	ng/L	12 <sup>2b</sup>	25	42	100	25	26

Notes:

Values are for dissolved metals, and represent depths between 0 and 33 feet in lake. Shaded cells exceed most stringent water quality standard.

AWQC

1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.

2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.

2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 65 mg/L as CaCO<sub>3</sub> was used for hardness, based on model predictions for hardness. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L, otherwise, 87 µg/L.

2b Aquatic life for fresh water (chronic) criteria.

2c Aquatic life for fresh water (acute) criteria.

2d Drinking water primary maximum contaminant levels.

2e Irrigation water criteria.

2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).

3 Represents Year 56 (complete mixing induced in Year 55).

4 Represents Year 56 (hurricane winds induced in Years 55 and 56).

Source: Lorax 2012, Table 4-2.

#### 4.4.2.5 Model Limitations

The initial Lorax modeling had some limitations that may have resulted in an under-estimate of predicted surface water concentrations. It assumed exhausted PAG runoff concentrations for PAG wall rock over the long term. However, pit walls are known to undergo periodic sloughing that expose fresh rock to weathering processes (e.g., Filipek 2004). Accordingly, the PAG runoff is more likely to have concentrations over time that range between those used in the model and those given in Table H-13 for peak oxidation rates. To test the effects of using peak PAG concentrations for runoff, Lorax conducted two additional PAG model runs for their “decreased salinity” case: 1) the conservative case, in which no reactions were allowed but PHREEQC was used to calculate pH of the mixed solutions; and 2) a reactive case allowing precipitation of low-temperature saturated aluminum, iron, and manganese oxyhydroxide minerals (Table H-16).

In both peak PAG, decreased salinity cases, the results were similar to the base case (within a factor of two for most constituents). Lake surface water concentrations of aluminum, antimony, arsenic, cadmium, lead, molybdenum, selenium, and mercury exceeded AWQC for all three cases. Copper exceeded AWQC in both peak PAG cases, but not in the base case. Manganese concentrations exceeded AWQC when not allowed to precipitate. The predicted pH in both peak-PAG cases is outside regulatory limits: The modeled pH was 5.2 for the no-reaction peak PAG case, and 5.1 with mineral precipitation.

When the AWT water management option was added to Alternative 2, Lorax (2015) developed another pit lake model using the revised water quality values from Table H-11 for the major inflow sources. The resulting predicted water quality for the uppermost 33 feet of the pit lake, shown in Table H-16, is similar to those predicted for the original water management plan. Aluminum, antimony, arsenic, cadmium, copper, iron, lead, manganese, molybdenum, selenium, and mercury concentrations exceeded AWQC. Although not modeled, pH was less than the lower AWQC limit (estimated to be between 5.0 and 6.0).

Table H-16: Surface Water Quality Estimates for Pit Lake at Closure Year 99 – Comparison of Exhausted-PAG (Base Case), Peak-PAG Pit-Wall Runoff (Decreased Salinity Case), and AWT Model

Parameter <sup>1</sup>	Units	AWQC	Base Case	Peak-PAG Case		AWT
			No Reaction <sup>2</sup>	No Reaction <sup>3</sup>	Mineral Precipitation <sup>4</sup>	No Reaction <sup>5</sup>
pH	Units	6.5 – 8.5 <sup>1</sup>	6.4	5.2	5.1	5.0 – 6.0
Sulfate	mg/L	25 <sup>01</sup>	31	48	48	41
Total Dissolved Solids	mg/L	500 <sup>1</sup>	139	143	97	125
Aluminum	µg/L	87 <sup>2a,b</sup>	310	590	97	1,530
Antimony	µg/L	6 <sup>2d</sup>	67	75	76	67
Arsenic	µg/L	10 <sup>2d</sup>	112	190	190	114
Boron	µg/L	750 <sup>2f</sup>	200	230	200	31
Cadmium	µg/L	0.18 <sup>2a,b</sup>	0.24	0.31	0.31	0.35

Table H-16: Surface Water Quality Estimates for Pit Lake at Closure Year 99 – Comparison of Exhausted-PAG (Base Case), Peak-PAG Pit-Wall Runoff (Decreased Salinity Case), and AWT Model

Parameter <sup>1</sup>	Units	AWQC	Base Case	Peak-PAG Case		AWT
			No Reaction <sup>2</sup>	No Reaction <sup>3</sup>	Mineral Precipitation <sup>4</sup>	No Reaction <sup>5</sup>
Chromium	µg/L	100 <sup>2e</sup>	4.0	4.3	4.3	4.6
Cobalt	µg/L	50 <sup>2e</sup>	3.0	5	5	6.5
Copper	µg/L	6.2 <sup>2a,b</sup>	1.4	7.1	6.7	10
Iron	µg/L	1000 <sup>2b</sup>	830	960	180	1,200
Lead	µg/L	1.6 <sup>2a,b</sup>	2.3	2.7	2.7	2.6
Manganese	µg/L	50 <sup>2f</sup>	128	170	15	176
Molybdenum	µg/L	10 <sup>2e</sup>	17	19	18	17
Nickel	µg/L	36 <sup>2a,b</sup>	11	20	20	19
Selenium	µg/L	4.6 <sup>2b</sup>	20	23	23	20
Zinc	µg/L	81 <sup>2a,c</sup>	13	45	47	53
Mercury	ng/L	12 <sup>2b</sup>	25	28	28	25

Notes:

Values are for dissolved metals, and represent depths between 0 and 33 feet in lake. Shaded cells exceed most stringent water quality standard.

**AWQC**

- 1 18 AAC 70. ADEC, Alaska Water Quality Standards. Amended as of April 8, 2012, maximum drinking water levels.
- 2 Alaska Water Quality Criteria Manual for Toxic and Other Deleterious Organic and Inorganic Substances. Amended through December 12, 2008. Most stringent criteria used. Criteria are expressed in terms of dissolved metal in the water column, except for aluminum and mercury, which are in terms of total recoverable metal.
  - 2a Aquatic life for fresh water hardness-dependent criteria. A hardness of 65 mg/L as CaCO<sub>3</sub> was used for hardness, based on model predictions for hardness. For aluminum, if pH ≥ 7.0 and hardness ≥ 50, then 750 µg/L, otherwise, 87 µg/L.
  - 2b Aquatic life for fresh water (chronic) criteria.
  - 2c Aquatic life for fresh water (acute) criteria.
  - 2d Drinking water primary maximum contaminant levels.
  - 2e Irrigation water criteria.
  - 2f Human health criteria for non-carcinogens (for consumption of water + aquatic organisms).
- 3 Lorax. 2014b. PitMod\_conservative\_monthly\_means.xls
- 4 Lorax. 2014c. PitMod\_mean monthly\_PHREEQC.xls. Aluminum, iron, and manganese low-temperature oxyhydroxide minerals were allowed to precipitate if saturated.
- 5 Lorax 2015; PitMod\_AWT2015.xlsx.

Another limitation was that the model did not address the role of ice melt in seasonal stratification and the potential for continued concentration of surface waters over time if more dilute ice melt is preferentially withdrawn for treatment and discharged each spring. However, the relatively low calculated TDS (on the order of 112 to 142 mg/L) for all but the complete mixing case suggest that the concentration effect due to ice formation would be minor.

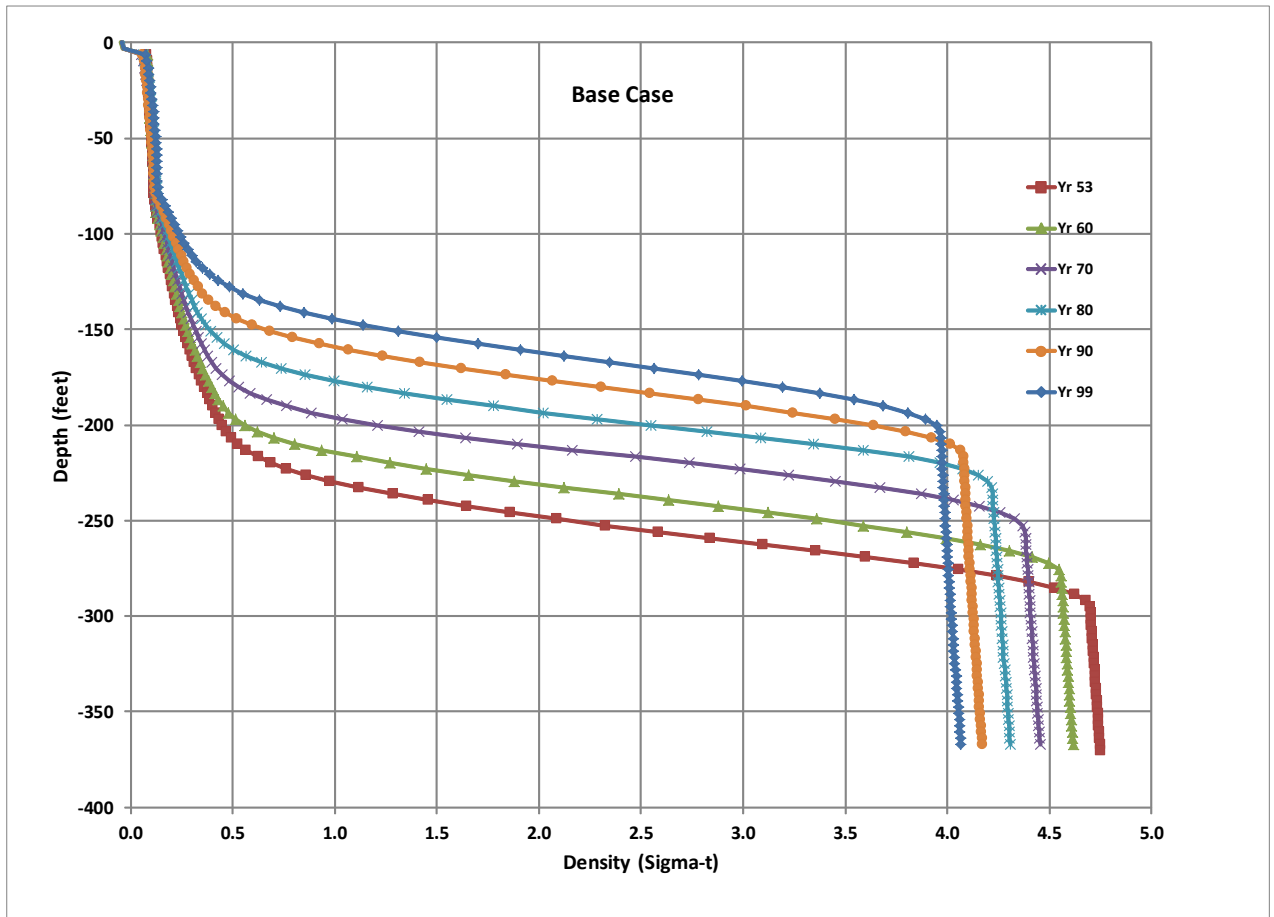
#### 4.4.2.6 Temporal Changes in Surface Water Quality and Pycnocline Depth

In all the modeled cases, pit lake surface-water concentrations appeared to reach steady state soon after the lake reached its maximum allowed elevation, so that the results for all but the Complete Mixing case for Year 53 are essentially identical to those shown in Table H-15 for Year

99. In contrast, the depth to the top of the pycnocline was found to decrease over time in all cases (Table H-4, Table H-5, and Table H-6; note change in scale of the density [ $\sigma_t$ ] axis between figures). As the pycnocline depth decreased over time, so did the concentration difference between the waters above and below the pycnocline.

The relative strengths of the pycnoclines for the base case; peak PAG, decreased salinity case; and the AWT case can be seen in Table H-7. For the base case, a gradual increase in density occurred between about 80 feet and 120 feet below the lake surface, with a rapid density increase (the pycnocline proper) starting at about 130 feet and continuing to about 200 feet below the surface. For the peak PAG, decreased salinity case, the total pycnocline zone was similar in thickness (starting at about 80 feet and ending at about 200 feet). However, the gradient was less sharp (i.e., the pycnocline is weaker), due to the smaller density difference between the waters above and below the pycnocline, suggesting that a decreased-salinity system could be more vulnerable to overturn and mixing throughout the water column than the base case. The strength of the pycnocline for the AWT case falls between the other two cases, due mainly to the lower TDS in the TSF seepage for the AWT water management plan than the original water management plan (Table H-12). The PAG cell seepage also changed; however, that seepage is only about one percent of the tailings pore water seepage while the pit lake is filling.

The modeled pycnocline moved up through the water column with time in all cases likely because each year additional water was fed through the pipe to the lake bottom and because of ongoing groundwater influx below the pycnocline, increasing the volume of water in the hypolimnion (i.e., below the pycnocline), while water was being removed and treated from above the pycnocline. Therefore, it would be expected that eventually the pycnocline would be close enough to the surface that wind and/or winter overturn would cause the lake to completely mix to the surface. Based on the complete mixing sensitivity run, after the lake overturns, the pit lake would likely eventually re-establish a pycnocline, but with higher constituent concentrations in the surficial layer, as occurred for the complete mixing case. The actual concentrations at the surface for the AWT case would likely be lower than for the complete mixing case due to the lower concentrations in the hypolimnion for the AWT case than for the base case (Table H-7).



Data Source: Lorax 2015



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**PROJECT EIS**

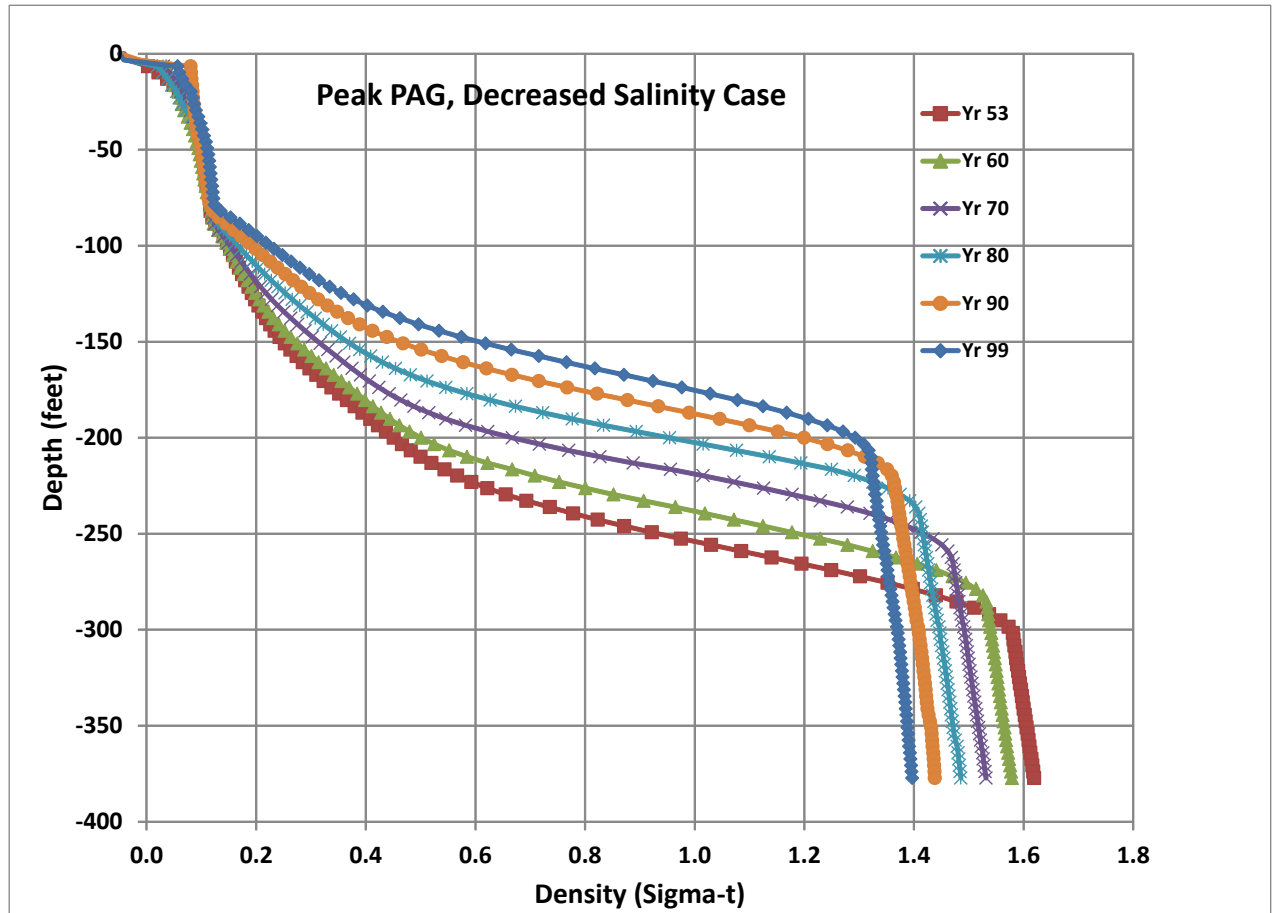


**Variation of Pycnocline Depth  
with Age of Pit Lake  
(53-99 Years) – Base Case**

NOVEMBER 2015

APPENDIX H FIGURE 4





Data Source: Lorax 2015



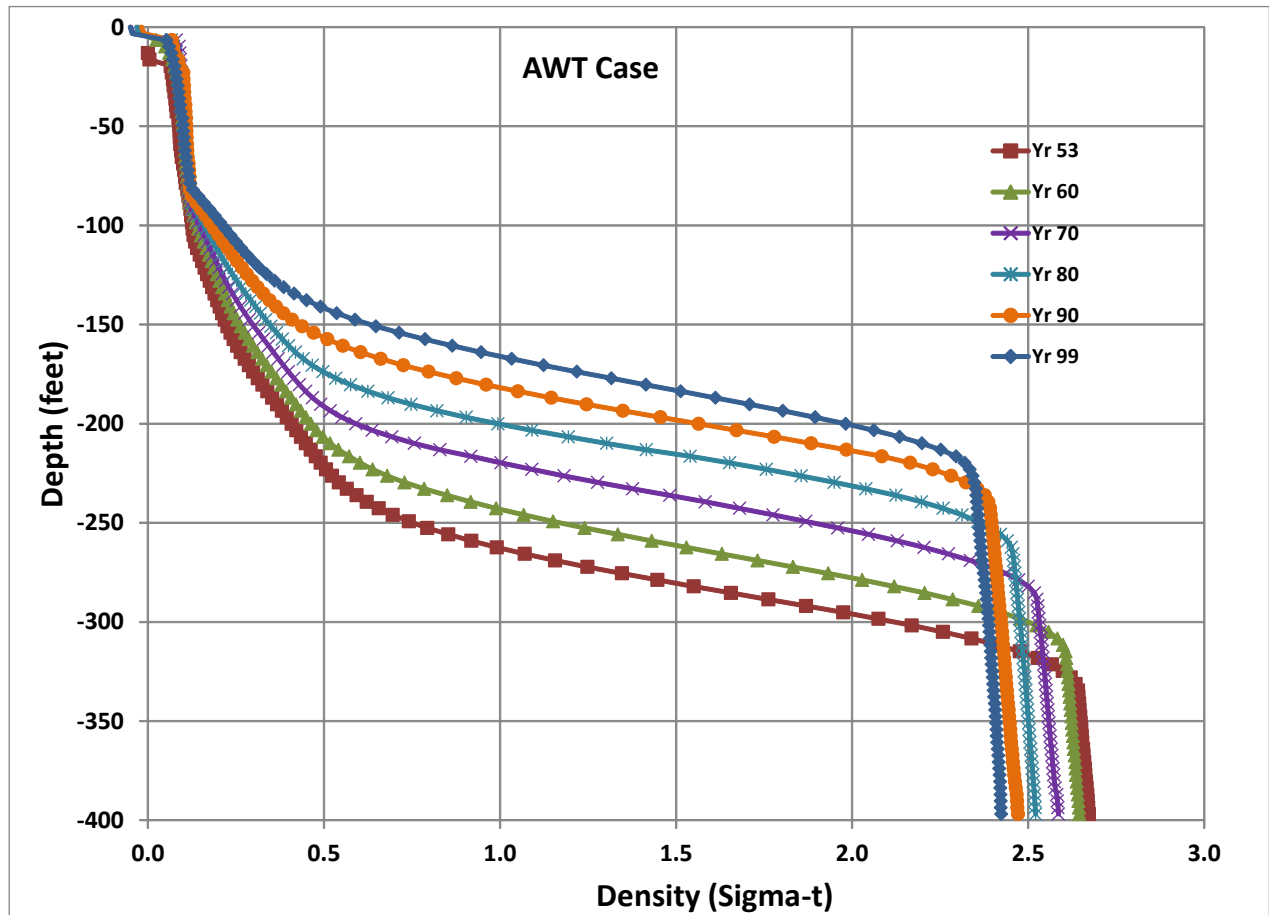
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**Variation of Pycnocline Depth  
with Age of Pit Lake  
(53-99 Years) – Peak PAG,  
Decreased Salinity Case**

NOVEMBER 2015

APPENDIX H FIGURE 5



Data Source: Lorax 2015



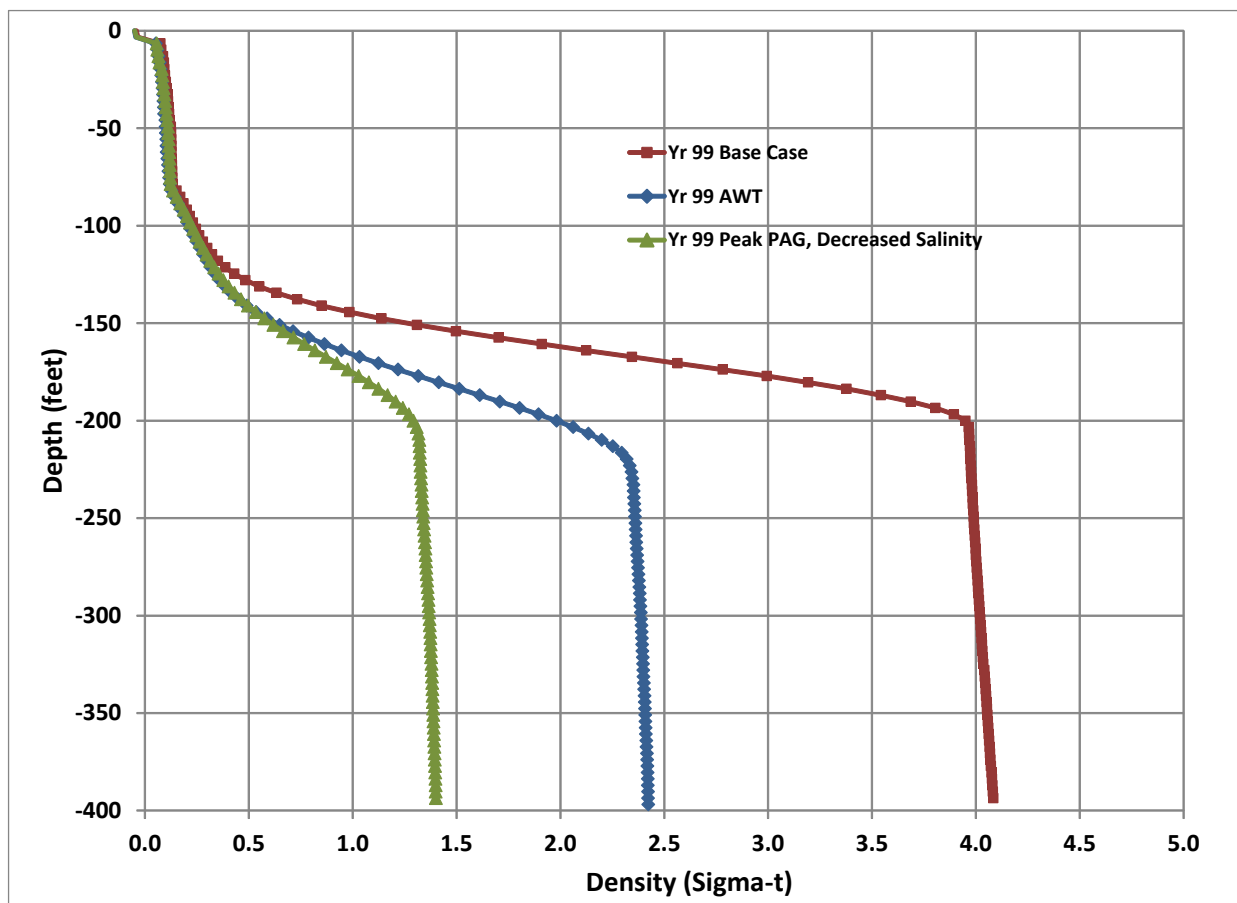
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**Variation of Pycnocline Depth  
with Age of Pit Lake  
(55 to 99 Years) – AWT Water  
Management Plan**

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APPENDIX H FIGURE 6



Data Source: Lorax 2015



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COMPARISON OF PYCNOCLINE DEPTH  
AND STRENGTH FOR THE BASE CASE,  
PEAK-PAG, DECREASED SALINITY  
CASE, AND AWT CASE (YEAR 99)

NOVEMBER 2015

APPENDIX H FIGURE 7

#### 4.4.2.7 Summary of Pit Lake Modeling

The results of the various modeling efforts of the predicted pit lake suggest that: the concentrations of several constituents in surface waters would exceed the most stringent AWQC throughout the 100-year modeling period, and the pycnocline is predicted to move upward toward the surface and become less intense over time, eventually reaching the surface at some point beyond the modeling period because each year water being added below the pycnocline and removed above it. For these reasons, additional mitigation measures that would help manage lake stratification, surface water quality, and water treatment in post-closure are provided in Chapter 5, Impact Avoidance, Minimization, and Mitigation.

### 5. Summary of Impacts for Alternative 2 – Geochemistry

Geochemistry describes the distribution, movement, and chemical reactions of elements in the environment, as well as processes affecting distribution, movement, and reactivity leading to effects on water quality. Because the changes that would occur from geochemical processes are reflected in water quality, the mitigation and cumulative effects associated with these changes are discussed in the EIS under Sections 3.7.3.2.2 and 3.7.3.2.3, Water Quality.